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Gerard H. Matthes

STATE OF OHIO

THE MIAMI CONSERVANCY DISTRICT

Rainfall and Runoff in the Miami Valley

BY

IVAN E. HOUK

District Hydrographer; Assoc. M. Am. Soc. C. E.

TECHNICAL REPORTS

Part VIII

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PREFATORY NOTE

This volume is the eighth of a series of Technical Reports issued in connection with the planning and execution of the notable system of flood protection works now being built by the Miami Conservancy District.

The Miami Valley, which forms a part of the large interior plain of the central United States and comprises about 4000 square miles of gently rolling topography in southwestern Ohio, is one of the leading industrial centers of the country. Out of the great flood of March, 1913, which destroyed in this valley alone over 360 lives and probably more than $100,000,000 worth of property, there resulted an energetic movement to prevent a recurrence of such a disaster by protecting the entire valley by one comprehensive project. The Miami Conservancy District, established in June, 1915, under the newly enacted Conservancy Act of Ohio, became the agency for securing this protection. On account of the size and character of the undertaking, the plans of the District have been developed with more than usual care.

A report of the Chief Engineer, submitting a plan for the protection of the District from flood damage, was printed in March, 1916, in three volumes of about 200 pages each. After various slight modifications, this report was adopted by the board of directors as the Official Plan of the District, and was republished in May, 1916, under the latter title. This plan for flood protection includes the building of five earth dams across the valleys of the Miami River and its tributaries to form retarding basins, and the improvement of several miles of river channel within the towns and cities of the valley. It is estimated that the dams will contain nearly 8,500,000 cubic yards of earth; that their outlet structures will contain nearly 200,000 cubic yards of concrete; that the river channel improvements will involve the excavation of nearly 5,000,000 cubic yards; and that the whole project will cost about $35,000,000.

At the time of the publication of this volume the flood control works are about three-fourths completed. The Germantown dam and a considerable portion of the channel improvement

work are entirely finished, and the remaining dams and channel work are rapidly approaching completion.

In order to plan the project intelligently many thorough investigations and researches had to be carried out, the results of which have proved of great value to the District and will also, it is believed, be of widespread use to the whole engineering profession. To make the results of these studies available to the residents of the State and to the technical world at large, the District is publishing a series of Technical Reports containing all data of permanent value relating to the history, investigations, design, and construction of the flood prevention works.

The following list shows the titles of the reports published to date and the price at which they may be purchased.

Part I.—The Miami Valley and the 1913 flood, by A. E. Morgan, 1917, 125 pages, 44 illustrations; 50 cents.

Part II.—History of the Miami flood control project, by C. A. Bock, 1918; 196 pages, 41 illustrations; 50 cents.

Part III.—Theory of the hydraulic jump and backwater curves, by S. M. Woodward. Experimental investigation of the hydraulic jump as a means of dissipating energy, by R. M. Riegel and J. C. Beebe, 1917; 111 pages, 88 illustrations; 50 cents.

Part IV.—Calculation of flow in open channels, by I. E. Houk, 1918; 283 pages, 79 illustrations; 75 cents.

Part V.—Storm rainfall of eastern United States, by the engineering staff of the District, 1917; 310 pages, 114 illustrations; 75 cents.

Part VI.—Contract forms and specifications, by the engineering staff of the District, 1918, 192 pages, 3 folding plates, and index; 50 cents.

Atlas of selected contract and information drawings to accompany Part VI; 139 plates, 11 by 15 inches; $1.50.

Part VII.—Hydraulics of the Miami flood control project, by S. M. Woodward, 1920; 344 pages, 126 illustrations; $1.00.

Part VIII.—Rainfall and runoff in the Miami Valley, by I. E. Houk, 1921; 236 pages, 51 illustrations; 75 cents.

Technical reports on the following subjects are contemplated.

Laws relating to flood control.

Structural design, construction plant and methods.

Methods of appraising property benefits and damages.

Orders for Technical Reports should be sent to:

The Miami Conservancy District, Dayton, Ohio.

Dayton, Ohio,
Jan. 1, 1921.

Arthur E. Morgan,
Chief Engineer.

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CHAPTER I.—INTRODUCTION

GENERAL

The purpose of this report is to present to the engineering profession the results of rainfall and runoff investigations carried on in connection with the Miami flood control project.

When an engineering examination of the Miami Valley was begun, immediately after the great flood of March, 1913, in order to determine the best plan for preventing damage by future floods, an investigation of rainfall and runoff conditions was naturally one of the first lines of attack. It was recognized at the start that a knowledge of rainfall and runoff would be essential in determining the size of the flood to be provided for, in the design of the flood protection works, and in the assessment of the benefits and damages which would result from the construction of the works, as well as in the many other problems which probably would be encountered as the development of the plans proceeded. However, as the work progressed and as the magnitude of the problem became apparent, the importance of collecting such data became even more pronounced than had been originally anticipated. Consequently the collection of rainfall and runoff records and the studies of rainfall and runoff relations were more or less gradually expanded during the first few years of the work.

While there were several rainfall stations in the Miami Valley at the time of the 1913 flood, there were but three river gages, one at Piqua, one at Dayton, and one at Hamilton. The work of establishing additional stations was begun, in cooperation with the U. S. Weather Bureau, almost immediately; and within a few months daily records of rainfall and river stages and periodic measurements of discharge were being obtained at several stations on the Mad and Stillwater Rivers, at Germantown on Twin Creek, and at several additional places on the Miami River. Arrangements were also made with the various observers for special readings of river gages during flood periods. The number of stations and the amount of flood data

being secured, was increased from time to time as the work progressed, as will be described in detail later.

Extensive hydrographic surveys of the 1913 flood in the Miami Valley, and investigations of the rainfall over the valley during that storm, were carried on during the summer and fall of 1913. Studies of the relation of the flood runoff to the storm rainfall were made as soon as the data was available. Similar studies for subsequent floods were made from time to time as the floods occurred.

As a practical aid in the study of the relation of runoff to rainfall, a number of small experimental plats were established at Moraine Park, about five miles south of Dayton, where rainfall and surface runoff could be measured on varying slopes and with varying soil conditions, as well as the rapidity and depth of soil saturation caused by different rains. After about four and a half years of records had been secured experiments were undertaken, using garden sprinkling cans to reproduce rainfall effects, in an effort to develop a method by which rainfall and runoff relations could be determined for a given watershed without waiting the comparatively long time required for the collection of sufficient data from natural rainfall. The results obtained were so suggestive that similar plats were established at the Taylorsville Dam where data could be obtained on different types of soil.

SCOPE OF THIS REPORT

Chapter II describes the rainfall and runoff records obtained in the Miami Valley. The records available at the time of the 1913 flood, the stations established since that time, the records secured at the various stations, the gages in use, and the methods of measurement are all discussed in detail. The actual records are not reproduced since the more valuable data is being published elsewhere. However, the places of publication, the particular records being published, and the manner in which the unpublished data may be secured are fully described.

Chapter III takes up the rainfall, runoff, and soil moisture data secured on the small experimental plats at Moraine Park. The records are given in full, in tables and diagrams, and are discussed in detail. The effects of variations in rainfall intensity and in soil moisture content on the surface runoff are taken up, as are also the total rainfall, runoff, and retention during storm

periods. A summary of the principal conditions shown by the data is given at the end of the chapter.

Chapter IV is devoted to the sprinkling experiments at Moraine Park and Taylorsville. The results are shown graphically, by means of mass curves. Summaries of the more important data are given in tabular form. An interesting relation was found to exist between rates of rainfall, runoff, and retention when the surface soil is saturated. The total rainfall, runoff, and retention during the various experiments, as well as the rates, are discussed in detail; and some data is given regarding the intensity and duration of precipitation before surface runoff begins.

In chapter V the monthly, seasonal, and annual rainfall, runoff, and retention throughout the Miami Valley are taken up. Annual conditions in the different drainage areas are shown by means of tables and diagrams. Monthly and seasonal conditions are discussed only for the drainage area above Dayton since the records available for the other stations are of comparatively short duration. A method of studying the hydrology of a valley by means of mass curves is shown, using the data for the drainage area of Mad River above Wright as an example. Discussions of the proportions of ground water runoff and flood runoff are included for the Stillwater, Mad, and Miami Rivers, and Buck Creek.

Chapter VI discusses the rainfall and runoff during the great flood of March, 1913. The data is shown by means of maps and diagrams, but the complete station records are not included. The distribution of the rainfall as regards time as well as drainage area, the characteristics of the flood hydrographs, and the relation of the flood runoff to the storm rainfall are discussed.

Chapter VII takes up the studies of rainfall and runoff which have been made for floods occurring since March, 1913. The total rainfall, runoff, and retention during flood periods; the maximum rates of rainfall and runoff; and the maximum values of retention are given in tabular form and are described in the text. Data is also included relating to storage in stream channels and on the ground, and to precipitation intercepted by trees. Brief descriptions of the various floods are given but the detailed rainfall and runoff records are not included.

Chapter VIII contains a brief description of the flood forecasting work of the District and of the methods used in making the forecasts.

ACKNOWLEDGMENTS

Acknowledgments are due the officials of the United States Weather Bureau, both in Washington and in Dayton, for their cooperation in establishing river and rainfall gaging stations and in maintaining records. All of the rainfall data used in this report except that obtained in the experimental work at Moraine Park, was secured from the Weather Bureau records. Acknowledgments are also due the U. S. Geological Survey, the U. S. Bureau of Soils, and other governmental bureaus.

The engineering organization engaged on the Miami flood control project up to the time construction began was described in detail in an earlier report.* The investigations described in this volume were conducted by the writer assisted at different times by G. N. Burrell, H. W. Wesle, B. H. Petty, H. R. Daubenspeck, F. E. Davis, and others. Professor S. M. Woodward in his capacity as consulting engineer for the District has been frequently consulted. The work has been outlined and supervised at all times by Arthur E. Morgan, chief engineer.

THE MIAMI VALLEY

Rainfall and runoff conditions vary so widely with variations in geology, topography, and climate that it seems pertinent to give a brief description of the Miami Valley.

As may be seen by referring to figure 1 the Miami River flows in a southwesterly direction through southwestern Ohio, entering the Ohio River at the Indiana and Ohio state line. It drains a rather fan shaped area of about 4000 square miles lying almost wholly in Ohio. The Whitewater River which joins the Miami near its mouth and which drains an area of about 1400 square miles lying almost entirely in Indiana, has not been shown since it is not affected by the works of the Miami Conservancy District.

The Miami River is about 163 miles in length. Its drainage basin, which includes parts of 15 counties, measures about 120 miles on the longer axis and about 70 on the shorter. The more important tributaries below Dayton, following northward up the west side of the Miami, are: Indian Creek, emptying just above Venice; Four Mile Creek, a flashy stream entering just above

*History of the Miami Flood Control Project, by C. A. Bock, Technical Reports, Part II, The Miami Conservancy District, Dayton, Ohio, 1918, page 115.

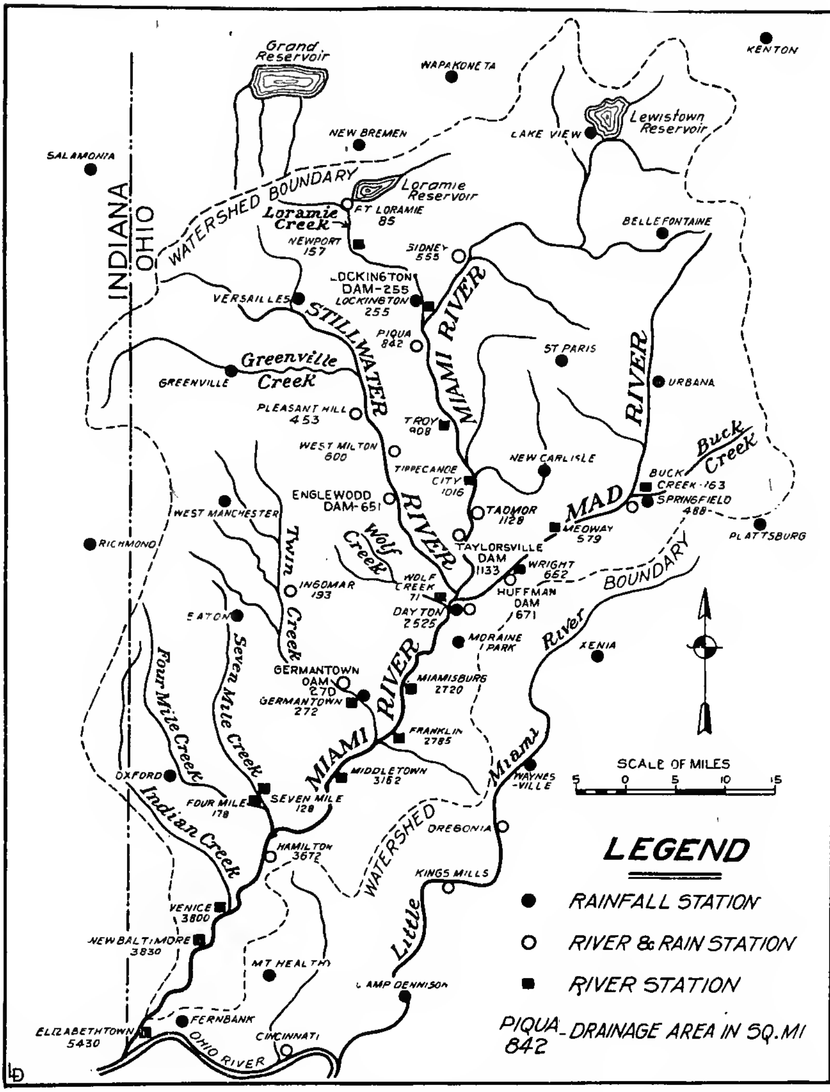

FIG. 1.—MAP OF MIAMI RIVER DRAINAGE AREA SHOWING GAGING STATIONS.

The drainage areas above the river stations, in square miles, are shown by the numbers placed under the names of the stations.

Hamilton; and Twin Creek, with its outlet just below Franklin. Seven Mile Creek flows into Four Mile Creek just above its junction with the Miami. Four streams, the Miami, Mad, and Stillwater Rivers, and Wolf Creek unite within the city limits

of Dayton. Just above Piqua, about 27 miles north of Dayton, the Miami is joined by Loramie Creek. Greenville Creek enters the Stillwater River from the west a few miles above Pleasant Hill. Buck Creek joins the Mad River from the east at Springfield.

The topography of the Miami Valley may be described as gently rolling with the general elevations of the uplands varying from about 800 feet above sea level near the mouth of the river to about 1100 feet near the headwaters. The slopes are comparatively flat near the headwaters but increase more or less gradually toward the southwest, being comparatively abrupt near the Ohio River. Except for its southernmost portion the entire basin bears evidence of having been covered by ice during the glacial period. The preglacial valleys carved in the limestone formations and the crests of the preglacial hills have been almost entirely obliterated by the ice. The Miami River and its principal tributaries flow in the partially filled valleys in comparatively insignificant channels.

The Miami River has a drop of about 2 feet per mile in the first 30 miles, and of about 3.3 feet throughout the major portion of its course. The Stillwater and Mad Rivers are somewhat steeper, the former sloping at a rate of about 4 feet per mile and the latter at a rate of about 6 feet. The smaller tributaries are still steeper, the slopes increasing as we proceed downstream. Twin, Four Mile, and Seven Mile Creeks are noted for the suddenness with which they rise and the short duration of their flood stages. The rolling topography, together with the fan shaped arrangement of the larger tributaries, present singularly favorable conditions for quick collection of storm runoff and the formation of high flood crests.

RAINFALL AND RUNOFF RELATIONS

Rainfall and runoff relations have been studied extensively during recent years. While more or less progress has been made, in methods of investigation as well as in final results, the problem is still far from a complete solution. Early investigators frequently tried to express runoff as a percentage of rainfall; more recently runoff has been considered as a residue remaining after the various losses are supplied. This was undoubtedly a step in advance, since runoff is, essentially, a residue remaining after the demands of evaporation, transpiration, and deep seepage are filled. However, these quanti-

ties, themselves, are so variable and are affected by so many factors that no simple accurate formulas for their calculation can be developed. It must be recognized that there is no simple relation between rainfall and runoff and that runoff can be determined from rainfall within narrow limits, only after very careful study of all existing data by experienced hydraulic engineers. Even then the results may be considerably in error.

This volume does not take up in a general way the factors affecting either rainfall or runoff. Neither does it give any general review of the work of other investigators. For such matters the reader is referred to the original publications and the more recent works on hydrology, listed in the bibliography at the end of the book. The purpose of this report, as before mentioned, is to present the results of the investigations which have been carried on in connection with this project. These were necessarily confined more to studies of actual rainfall and runoff conditions in this valley than to the general laws affecting such phenomena. It will be valuable, however, to point out briefly the more general conclusions regarding rainfall and runoff relations in the Miami Valley, which seem to be justified by the data contained herein.

The Moraine Park records taken up in chapter III show:

1. That variations in surface slope are of much less importance as affecting runoff than are variations in vegetable cover.

2. That intensity of precipitation has an important effect on the occurrence and amount of surface runoff.

3. That during the summer months rainfall seldom percolates to such depths that it is not raised again by capillarity or by root action and evaporated or transpired back into the atmosphere.

4. That storage in the surface soil, filled during winter rains, furnishes about 5 inches of water to the summer evaporation and transpiration requirements.

The sprinkling experiments described in chapter IV show:

5. That the rate of surface runoff increases as the rate of precipitation increases, the former being directly proportional to the latter when the surface soil is saturated.

6. That the rate of percolation, when the surface soil is saturated, increases as the rate of rainfall increases, the variation being according to a straight line equation and the rate of

increase being proportionally greater for loose loamy soils than for heavy clay soils.

7. That cultivation has a relatively important effect in reducing the amount of surface runoff.

The studies of annual runoff given in chapter V show:

8. That annual evaporation, including transpiration, is not constant, but varies with the seasonal distribution and amount of rainfall, as well as with other meteorological factors, the variation for the drainage area above Dayton being slightly greater than the variation in annual rainfall.

9. That annual runoff is much more variable than either annual rainfall or annual evaporation.

10. That annual surface, or flood, runoff is much more variable than the annual low water, or ground water, runoff, the variations in total annual runoff being caused primarily by the variations in surface runoff.

11. That the character and condition of the soil influences runoff to a greater extent than has been generally recognized, and next to rainfall is the most important factor affecting runoff.

The studies of storm rainfall and flood runoff taken up in chapter VII show:

12. That the total retention during similar storms is greater in the summer than in the winter.

Some of the above conclusions are simply confirmations of recognized laws. Others, however, such as number 6, relating to the rate of percolation, are new.

It is believed that the sprinkling method of investigating rainfall and runoff relations, described in chapter IV, offers distinct possibilities; and it is hoped that other investigators will try this out in different parts of the country and on different soils. Of course whenever sufficient funds are available it would be desirable to install lysimeters so that the percolation can be directly measured. Such experiments might be taken up by senior or graduate students at the various technical colleges. Persons desiring to pursue the matter might secure rainfall and runoff data, similar to that contained in chapter IV, for different soils, at different seasons of the year, with different surface coverings, and in different stages of cultivation. Data might also be secured on the intensity and duration of precipitation which will cause surface runoff to begin on different soils, covered with different growing crops

in different stages of growth. Engineers engaged on projects requiring a knowledge of rainfall and runoff relations can probably secure valuable information in a few months by such methods.

Better information regarding variations in soil absorption, percolation, evaporation, and transpiration caused by variations in soil texture, soil moisture, temperature, rainfall, surface conditions, and so forth, will be of material assistance in studies of flood runoff and storm rainfall. Probably future studies of the relation between rainfall and runoff will give better results if the flood runoff and low water runoff are considered separately, even though the division between the two may have to be more or less arbitrarily made. This should be especially true where the flood runoff constitutes a large proportion of the total and is as variable as it is in the Miami Valley.

Records of total rainfall and runoff should be published whenever possible, since such information always is valuable to hydraulic engineers. From a large accumulation of such records certain generalizations sometimes can be made. Where the records are of long duration they furnish valuable data for studies of abnormally dry and wet years as well as of the general variations in total amounts. However, such data is of limited application in that it includes the cumulative effects of the different fundamental laws affecting these phenomena, and it is doubtful whether a detailed study of such records will indicate very definite relations between the two which can be blindly applied to other drainage areas.

CHAPTER II.—RAINFALL AND RUNOFF RECORDS

RECORDS PRIOR TO 1913

In May, 1913, when the Miami Valley flood prevention surveys were begun, the United States Weather Bureau maintained the only gaging stations within the Miami River drainage area above the mouth of the Whitewater. There were eight of these, located at Springfield, Urbana, Bellefontaine, Sidney, Piqua, Greenville, Dayton, and Hamilton. A few additional stations, also maintained by the Weather Bureau, were located just outside the valley at Kings Mills, Waynesville, Plattsburg, Kenton, Wapakoneta, and New Bremen, Ohio, and at Richmond and Salamonia, Indiana.

Daily rainfall records were being secured at all places. At some stations the records had been taken for comparatively long periods of time. At Dayton, for instance, continuous records had been taken since November, 1882; and at Urbana, during the period from January, 1852, to April, 1878, and after January, 1896. At Greenville, continuous records had been taken since February, 1886.

Rainfall records were also available at a few stations which had been established, and later discontinued, by the Weather Bureau. Among these might be mentioned the 10-year records at Bethany and Oxford, Butler County, and at New Paris, Preble County, and the 40-year record at Jacksonburg, Butler County.

However, the river gage records were much fewer in number. Of the above mentioned eight stations within the Miami Valley, river records were being secured at only three, Piqua, Dayton, and Hamilton. At Piqua, flood stages had been observed from January 1, 1907, to December 31, 1910, and daily stages after January 1, 1911. At Dayton, continuous daily stages had been observed beginning December 22, 1892. At Hamilton, flood stages had been observed from November 15, 1904, to February 28, 1910, and daily stages beginning with March 1, 1910.

The Water Resources Branch of the U. S. Geological Survey had maintained a river station on Mad River, about four miles west of Springfield, from December 31, 1903, to March 31, 1906; during which time they secured daily gage readings, except for

certain short periods during the winter months, and made several measurements of discharge. They had also developed a satisfactory rating curve for the channel at Hamilton, for stages up to about twenty feet, and had made a number of low water discharge measurements at Dayton.

In addition to the above, a few records of maximum flood heights at Dayton were available in the early histories and newspapers of the Miami Valley.

Dayton was made a regular Weather Bureau station in August, 1911. From that time the usual meteorological records taken at such stations were available for Dayton, including the automatic records of sunshine, wind velocity, wind direction, and precipitation, made by the triple register, as well as the records of barometric pressure, relative humidity, temperature, and the like.

STATIONS ESTABLISHED SINCE 1913

The river records being secured in 1913 were, of course, inadequate for the flood prevention studies. While the rainfall records were fairly satisfactory for investigations involving the entire drainage area, they, also, were inadequate for the intensive studies which would be required for the smaller tributaries. Consequently steps were at once taken, in cooperation with the U. S. Weather Bureau, to secure additional stations.

During the years 1913 and 1914 sixteen new stations were established as follows:

1. Rainfall stations, established by the U. S. Weather Bureau, at New Carlisle, Lake View, Versailles, St. Paris, Mt. Healthy, Fernbank, and Germantown.

2. Rainfall and river stations, established by the Dayton Flood Prevention Committee in cooperation with the U. S. Weather Bureau and maintained by the Weather Bureau, as follows:

Sidney—On the Miami River
Tadmor—On the Miami River
West Milton—On the Stillwater River
Springfield—On the Mad River

3. River stations established by the Dayton Flood Prevention Committee:

Germantown—On Twin Creek
Wright—On Mad River
Seven Mile—On Seven Mile Creek

Four Mile—On Four Mile Creek
Springfield—On Buck Creek

Since 1914 additional rainfall stations have been established by the U. S. Weather Bureau at Oxford, West Manchester, Eaton, Xenia, and Marysville.

A rainfall station was established by the Weather Bureau at Woodstock in August, 1916, but owing to the difficulty of securing satisfactory records the station was discontinued a few months later. The Dayton Flood Prevention Committee established a rainfall station at Moraine Park, about five miles south of Dayton, in March, 1915.

In the fall of 1915 the Miami Conservancy District, which had taken over the work of the Dayton Flood Prevention Committee, established a river station on Loramie Creek at Lockington. In the spring of 1916, after the retarding basin plan of flood control had been decided upon, the District established eleven new river stations as follows:

Fort Loramie—On Loramie Creek
Newport—On Loramie Creek
Troy—On Miami River
Tippecanoe City—On Miami River
Miamisburg—On Miami River
Franklin—On Miami River
Middletown—On Miami River
Pleasant Hill—On Stillwater River
Medway—On Mad River
Ingomar—On Twin Creek
Dayton—On Wolf Creek

The stations on Loramie and Twin Creeks, on the Stillwater and Mad Rivers, and the Troy and Tippecanoe City stations on the Miami River, were located within the proposed retarding basins. The primary purpose in establishing these was to secure records of flood heights, before the dams were started, for use in settling questions that may arise when construction work is finished. The stations on Wolf Creek and on the lower Miami River, at Miamisburg, Franklin, and Middletown, were established primarily for use in flood forecasting. A station on the Miami River at Elizabethtown, near the mouth of the river, was established for the same purpose in June, 1918. A station on the Miami at New Baltimore was established by the Local Weather Bureau Office at Cincinnati, January 14, 1916, for use in forecasting flood stages on the Ohio River.

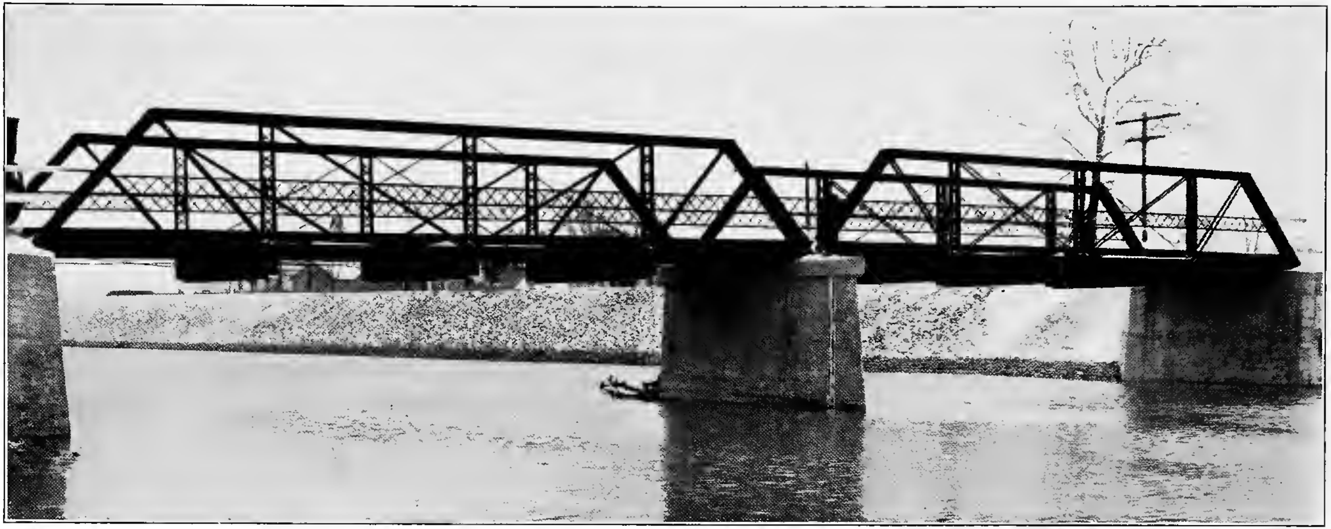

FIG. 2.—GAGING STATION ON LORAMIE CREEK AT LOCKINGTON.

The U. S. Engineer Office, First Cincinnati District, established a river station on the Miami at Venice in June, 1915, and maintained records until July 1, 1920. At that time the Conservancy District established a gage and continued the records.

In the summer of 1918, after the construction of the flood prevention works had gotten under way, the Miami Conservancy District established river and rainfall stations at the Germantown, Englewood, Taylorsville, and Huffman Dams, a rainfall station at the Lockington Dam, and also installed rain gages at the Fort Loramie, Pleasant Hill, and Ingomar stations. A river gage was installed at Miller's Ford, just south of Dayton, in August, 1919, for use in determining discharges at Dayton during the progress of the river improvement work, since this work affected the rating curve for the Main Street section where the gage has always been located.

Figure 1, page 17, shows the gaging stations being maintained in September, 1919. Different symbols are used to distinguish between the rainfall, river and rainfall, and river stations, but no distinction is made between stations maintained by the U. S. Weather Bureau and those maintained by the Miami Conservancy District. Table 1 gives pertinent data relating to the various river stations, including the authorities maintaining the records. Figure 2 shows the station on Loramie Creek at Lockington.

A cable station, for use in measuring the larger floods, was installed by the District at Taylorsville, about two miles south of the Tadmor station, in May, 1916. A view of this station is shown in figure 3. The old Miami and Erie Canal crosses the valley on a fill at this place, thus causing the entire flow during large floods to be contracted from a width of about a half mile to a width of about 280 feet.

Automatic recording river gages, of the electric transmission type, were installed by the District at the Dayton and Hamilton stations in the spring of 1917. These gages are located in the offices of the District and consequently furnish accessible information regarding river stages at all times.

Four small plats, where the rainfall, runoff, and soil absorption could be measured, were established at Moraine Park, about five miles south of Dayton, in March, 1915. A standard rain gage was installed at the writer's residence in June, 1916; and a second gage was installed under the trees at the same place in July, 1919, in order to determine the amount of rainfall inter-

Table 1.—Data Relating to River Gaging Stations in the Miami Valley

Station	Stream	Location of Gage	Established	Elevation of Zero†	Flood Stage	Width at: Average Low Water Feet	Width at: Bank Full Stage Feet	Lowest Known Water: Stage	Lowest Known Water: Date	Highest Known Water: Stage	Highest Known Water: Date	Maintained by	Records	Drainage Area Square Miles
Sidney	Miami River	North St. Br.	2– 1–14	926.46	10	110	260	— 1.5	9–19–17	17.9	3–25–13	U.S.W.B.	daily	555
	*		* 9–19–19	924.65	12									
Piqua	" "	N. Main St. Br.	8– 4–05	......	14	300	350	0	1–16–10	23.3	3–25–13	"	⊙ "	842
			* 5– 1–10	849.10	12									
Troy	" "	Broadford Br.	4– 5–16	810.74	9	165	265	0.5	7–30–19	14.2	3–25–13	M.C.D.	"	908
			* 7– 9–16	809.24										
TippecanoeCity	" "	Carlisle Pike Br. 1 mi. E. of town	3–20–16	783.7	8	100	250	0.2	2– 8–18	15.	3–25–13	"	"	1016
Tadmor	" "	National Pike Br.	12–22–13	763.68	12	160	250	1.7	8–21–17	25.4	3–25–13	U.S.W.B.	"	1128
Taylorsville	" "	R. R. trestle above dam	7–29–18	700.	70	340	420	63.6	8–22–18	81.7	3–25–13	M.C.D.	"	1133
Dayton	" "	Main St. Br.	10– 1–92	723.73	18	350	600	0	10–27–95	29.0	3–26–13	U.S.W.B.	"	2525
Miamisburg	" "	Linden Ave. Br.	3–14–16	681.09	....	350	665	0.3	8–14–19	31.0	3–26–13	M.C.D.	"	2720
			* 9– 5–16	680.09	17									
Franklin	" "	Suspension Br.	3–15–16	658.41	17	260	365	0.7	10–18–17	23.0	3–26–13	"	"	2785
Middletown	" "	Third St. Br.	6–22–16	624.65	17	250	300	1.0	7–11–18	29.0	3–26–13	"	"	3162
Hamilton	" "	High St. Br.	11–16–04	564.56	12	450	500	0.1	8–27–19	38.5	3–26–13	"	§ "	3672
Venice	" "	Highway Br. ½ mi. S. E. of town	6–14–15	520.22	16	265	355	1.2	11– 6–17	38.0	3–26–13	WarDep.	"	3800
			* 6–28–20	518.42	18							M.C.D.	"	
New Baltimore	" "	Highway Br.	1–14–16	504.0	25	340	485	......	....	38.0	3–26–13	U.S.W.B.	flood	3830
Elizabethtown	" "	Highway Br. ½ mi. S. E. of town	6–12–18	453.33	9	300	700	— 0.6	6–14–18	38.6	2–14–84	M.C.D.	daily	5430
Dayton	" "	Highway Br. at Miller's Ford	9– 7–19	712.86	15	300	470	0.2	9–13–19	27.	3–26–13	"	"	2600
Fort Loramie	Loramie Creek	Highway Br. W. side of town	4–14–16	933.05	6	18	122	0.7	8–14–16	16.0	3–25–13	"	"	85

*Reset. †Mean Sea Level Datum. ⊙Flood Stages 1-10-07 to 1-11-11. §Flood Stages 11-16-04 to 2-28-10. *New Gage.

Table 1.—*Continued*

Station	Stream	Location of Gage	Established	Elevation of Zero†	Flood Stage	Width at: Average Low Water Feet	Width at: Bank Full Stage Feet	Lowest Known Water: Stage	Lowest Known Water: Date	Highest Known Water: Stage	Highest Known Water: Date	Maintained by	Records	Drainage Area Square Miles
Newport	Loramie Creek	Highway Br. ¼ mi. S. of town	4–13–16	923.90	8	15	110	0	8–15–19	15.0	3–25–13	M.C.D.	daily	157
Lockington	" "	Highway Br. ½ mi. W. of town	9–13–15	875.99	7	112	112	0.8	8–29–18	15.6	3–25–13	"	"	255
Pleasant Hill	Stillwater River	Highway Br. ½ mi. N. W. of town	4– 7–16	846.55	13	200	249	1.2	1– 1–17	17.5	3–25–13	"	"	453
West Milton	" "	C.C.C.&St.L.R.R. Br. near Troy Pk.	1– 3–14	812.97	7	110	200	0.5	8–27–18	28.0	3–25–13	U.S.W.B.	"	600
Englewood	" "	R. R. trestle above dam	5– –18	0.	780	190	220	773.	7– 6–19	793.8	3–25–13	M.C.D.	"	651
Springfield	Buck Creek	Plum St. Br.	7–13–14	908.20	7	70	90	0.3	12–20–17	12.3	3–25–13	"	"	163
Springfield	Mad River	Old Mill S. of C.C. C.&St.L. Br. #121	2– 5–14	887.81	10	50	100	1.0	8–22–18	19.2	3–25–13	U.S.W.B.	"	488
Medway	" "	Highway Br. 1 mi. S. E. of Medway	3– 7–16	837.16	8	85	145	0.3	12–17–17	....	3–25–13	M.C.D.	"	579
Wright	" "	Covered Highway Br. at Simms	11–19–14	783.91	7	70	200	0.8	9–15–19	14.0	3–25–13	"	"	652
Huffman	" "	200 ft. above R. R. trestle above dam	6– 6–18	780.	6	120	145	1.4	8–24–18	12.5	3–25–13	"	"	671
Dayton	Wolf Creek	First Highway Br. above city	6–12–16	743.76	12	30	75	......	....	14.5	3–25–13	"	flood	71
Ingomar	Twin Creek	Highway Br. 1½ mi. W. of town	4–12–16	815.42	12	115	257	0	9–16–19	28.0	3–25–13	"	daily	193
Germant'n Dam	" "	Sump above dam	6– 1–19	720.	10	150	175	3.0	11– 4–13	26.0	3–25–13	"	"	270
Germantown	" "	Highway Br. 1 mi. W. of town	4– 9–14	714.0	7	100	200	0.6	10– 4–19	17.0	3–25–13	"	"	272
			*8–14–14	712.73	8					18.3				
Seven Mile	Seven Mile Creek	Covered Br. ¼ mi. W. of town	11–16–14	623.10	10	25	200	1.1	11–16–14	17.0	3–25–13	"	"	128
Four Mile	Four Mile Creek	H. Br. Eaton Rd. N.W. of Hamilton	11–17–14	618.69	7	15	100	0.9	8–25–18	18.0	3–25–13	"	"	178

*Reset. †Mean Sea Level Datum.

cepted by trees. Plats similar to those at Moraine Park were established at the Taylorsville Dam in July, 1920, so that rainfall and runoff experiments could be carried on, using a sprinkling can to reproduce rainfall effects.

RECORDS BEING SECURED

Daily rainfall records, including notes regarding the times of beginning and ending of the rain, are being secured at all but one or two of the rainfall stations shown in figure 1. In addition, automatic graphical records of rainfall and river stage are being secured at Dayton. Similar automatic rainfall records are, of course, being taken at several regular Weather Bureau stations surrounding the Miami Valley, such as Cincinnati, Indianapolis, Fort Wayne, Columbus, and Toledo. Daily records of gage heights are being secured at all river stations except New Baltimore and the one on Wolf Creek, where only flood records are being secured.

The daily river and rainfall observations taken at the Weather Bureau stations are recorded on the usual forms and are reported at the end of each month. Observers at some of the stations shown on figure 1 send their reports to the local Weather Bureau office at Dayton. The others report to the office at Columbus. Observations taken at the Miami Conservancy District's stations are recorded on postal card forms and are mailed to the headquarter's office at Dayton at the end of each week.

Special highwater readings of the river gages, for use in determining flood hydrographs, are being secured by the District at the following stations:

Sidney—On the Miami River
Piqua—On the Miami River
Tadmor—On the Miami River
Miamisburg—On the Miami River
Franklin—On the Miami River
Middletown—On the Miami River
Lockington—On Loramie Creek
West Milton—On Stillwater River
Springfield—On Buck Creek
Springfield—On Mad River
Wright—On Mad River
Dayton—On Wolf Creek
Germantown—On Twin Creek
Seven Mile—On Seven Mile Creek
Four Mile—On Four Mile Creek

FIG. 3.—CABLE GAGING STATION ON MIAMI RIVER AT TADMOR.

During the flood of March, 1913, the entire flow of the Miami River at Tadmor passed between the abutments shown in the picture, destroying the bridge superstructure and the two piers.

In general, these readings are taken every hour during the rising flood, every two hours during the day following the time of maximum stage, and then three times each day until the water has fallen to about the stage existing before the rise began. Each day's readings are recorded on a special postal card form and mailed to the headquarter's office as soon as possible.

Special reports from the greater number of both river and rainfall stations, for use in forecasting flood heights, are made direct to the Conservancy District during critical periods, as well as to the Weather Bureau. These reports are made by telephone or telegraph as soon as the rainfall amounts to 0.70 of an inch, provided it has fallen in 24 hours or less; or whenever there is a sudden rise in the river stage amounting to three feet or more. A confirmation of each report is made by mail as soon as the message has been telegraphed or telephoned. These reports make possible the accurate forecasting of flood conditions and also furnish valuable information regarding flood runoff and storm rainfall.

Rainfall measurements are recorded to the nearest hundredth of an inch. Where the precipitation is less than a hundredth of an inch the amount is indicated by a capital "T" meaning "trace." River gage readings are observed and recorded to the nearest tenth of a foot at all stations except Venice. At Venice, where the gage is of the Mott type, the observations are taken to the nearest hundredth of a foot.

Readings to hundredths of a foot may be practicable at times during ordinary and low water stages where the stations are equipped with chain and weight or Mott gages, or with vertical staff gages graduated to hundredths. However, where the gages are of the vertical staff type, graduated to tenths only, it is doubtful if such precision is ever warranted, especially where the observers have had no technical training, as is generally the case. During flood conditions, or if there is a strong wind blowing, the water will rise and fall, intermittently, from a tenth to a half a foot or more; so that readings to hundredths, while mechanically possible with certain gages, are accurate only to tenths of a foot at the best.

GAGES IN USE

Standard U. S. Weather Bureau rain and snow gages are being used at all rainfall stations. The regular Weather Bureau station at Dayton is also equipped with tipping bucket gage.

A chain and weight river gage is in use at the New Baltimore station, and Mott tape gages at Piqua and Venice. The other river stations are equipped with vertical staff gages. Automatic recording river gages of the electric transmission type are in use at Hamilton and Dayton.

The engineers of the Miami Conservancy District prefer the vertical staff gage to any other type, leaving out of consideration the sloping gages which are so expensive that they are feasible only in exceptional cases. The principal objection to the chain and weight gage is that the chain gradually stretches, thus requiring the continual checking of the chain length and the correcting of the observer's reports. Another objection, which applies also to the Mott gage, is that the boxes, having a somewhat mysterious appearance, are frequently broken into and the gages damaged.

DISCHARGE MEASUREMENTS

Measurements of discharge are made by the District at all river stations in the valley except New Baltimore and the Germantown, Englewood, Taylorsville, and Huffman dams. Measurements are not made at these places since they are close to the other stations and since the conditions due to the construction work are unfavorable for the securing of accurate data. The station at Venice was well rated by the engineers of the War Department, First Cincinnati District, during the flood of July, 1915.

Measurements are made during flood periods and more or less periodically during normal or low water conditions. They serve to determine the relations between gage heights and discharge, thus enabling the calculation of station rating tables and the compilation of daily stream flow records. Moreover, the inspections by the hydrographers furnish checks on the accuracy of the observer's readings and also supply information regarding channel conditions, effects of vegetation on stages, and the like.

Periodic measurements of discharge are also made on various artificial channels, carrying water for industrial use, as follows:

Miami and Erie Canal north of Fort Loramie
Miami and Erie Canal Feeder at Sidney
Tail Race at Slusser-McLean Company's Plant at Sidney
Miami and Erie Canal at Lockington
Miami and Erie Canal Feeder north of Lockington

Miami and Erie Canal at Piqua
Tail Race at Waterworks Pumping Plant at Piqua
Miami and Erie Canal at Troy
Mill Race at Troy
Miami and Erie Canal at Tippecanoe City
Head Race at Tranchant & Finnell Mills at Osborn
Miami and Erie Canal Feeder at Findlay Street, Dayton
Miami and Erie Canal Feeder Wasteway below Findlay Street, Dayton
Miami and Erie Canal at Warren Street, Dayton
Dayton Hydraulic Company's Canal at Findlay Street, Dayton
Miami and Erie Canal at West Carrollton
Hydraulic Canal at West Carrollton
Miami and Erie Canal at Miamisburg
Tail Race at Grove & Weber Co.'s Plant, Miamisburg
Tail Race at Ohio Paper Co.'s Plant, Miamisburg
Tail Race at Miamisburg Paper Co.'s Plant, Miamisburg
Miami and Erie Canal at Franklin
Hydraulic Canal at Franklin
Miami and Erie Canal at Middletown
Hydraulic Canal at Middletown
Miami and Erie Canal at Hamilton
Hydraulic Canal above Reservoir at Hamilton
Hydraulic Canal at Niles Tool Works, Hamilton
Old River at Hamilton
Head Race at Bentel Margedant Plant, Hamilton
Wasteway at Ohio Electric Power Plant, Hamilton

These measurements furnish the information needed in benefit and damage assessments as well as in design of local channel improvements. They also furnish the additional data needed in calculating total runoff at river stations. Gagings at some of the above sections have recently been discontinued due to changes made in connection with the construction work.

All gagings are made with the small Price current meter, combination type, using the penta commutator whenever the velocities are so high that single revolutions of the meter cannot be accurately counted. Observations are taken by the two-point method whenever feasible. During low water conditions measurements are made by wading, using the six-tenths depth method if the water is less than two feet deep. During floods it is frequently necessary to resort to the surface method. In such cases coefficients of from 0.8 to 0.9 are used to reduce the surface

velocities to mean velocities, the particular coefficient used in a given case being determined from a study of vertical velocity curves taken at the given station. Stay lines have been used in some cases.

The two-point method of measurement has been tested by about fifty vertical velocity curves, taken at various locations among the fifty odd gaging stations, in artificial as well as natural channels. The average of the ratios of the velocity by the two-point method to the velocity determined from the curve was found to be 0.994; the average error of the two-point method, obtained by averaging, arithmetically, the differences between the ratios and unity, was 1.24 per cent; and the maximum error for a single curve was 7.5 per cent.

Gage readings are taken before and after each measurement, to the nearest half tenth of a foot wherever practicable. Soundings are recorded to the nearest tenth. Observations are taken in at least ten but not more than twenty vertical sections during each gaging, regardless of the width of the stream. If the velocity varies greatly across the stream the sections are spaced closer together than usual.

In computing discharges from field notes the velocities and depths measured in a given vertical are assumed to represent average conditions in a width of channel extending, on each side, half way to the adjacent verticals. This method has been found to give fully as satisfactory results as the method of averaging velocities and depths in adjacent vertical sections to get the average conditions in the width of channel between sections. The latter method requires two operations not necessary in the former.

Current meters are rated at least once each year, more frequently if necessary. However, the experience of the Miami Conservancy District has been that the ratings of individual instruments, where the instruments have received proper care, seldom differ more than one or two per cent from the composite table furnished by the manufacturers.

The meters were formerly rated by the Bureau of Standards at Washington. Recently, however, they have been rated in the river at Dayton, at a location just above an old concrete dam, where still water exists. Ratings are made with the meters suspended by cables and held in place by lead torpedo weights, the conditions being made as nearly as possible like those under which the meters are used.

STREAM FLOW RECORDS

Daily stream flow records are being compiled for the following stations:

Sidney—On the Miami River
Piqua—On the Miami River
Tadmor—On the Miami River
Dayton—On the Miami River
Franklin—On the Miami River
Hamilton—On the Miami River
Venice—On the Miami River
Lockington—On Loramie Creek
Pleasant Hill—On Stillwater River
West Milton—On Stillwater River
Springfield—On Buck Creek
Springfield—On Mad River
Wright—On Mad River
Germantown—On Twin Creek
Seven Mile—On Seven Mile Creek
Four Mile—On Four Mile Creek

The records are tabulated on forms similar to those used by the U. S. Geological Survey, one sheet being used for each year at each station. These sheets give the daily stages and discharges, the mean monthly discharges in second feet and in second feet per square mile, the monthly runoff in inches depth over the drainage area and in acre feet, the maximum and minimum discharges for each month, the total runoff for the year, and the mean, maximum, and minimum rates of runoff for the year.

The records are believed to be as accurate as it is feasible to determine such data on streams similar to those in the Miami Valley. They are, of course, more accurate for the larger streams having the flatter slopes than for the smaller streams having the steeper slopes. The records for the Four Mile Creek station are more unsatisfactory than those for any other station in the valley, due to the shifting of the control during floods. This shifting occurs during small rises of two or three feet as well as during the larger floods, owing to the sand and gravel deposits at the station and to the steep slope of the stream, about fifteen feet per mile.

PUBLICATION OF DATA

The daily rainfall records at Weather Bureau stations are published by the U. S. Weather Bureau in their "Climatological

Data." The records at the Miami Conservancy District's stations are not being published.

Daily gage heights at the river stations maintained by the U. S. Weather Bureau are published annually in their "Daily River Stages at River Gage Stations on the Principal Rivers of the United States." Summaries of discharge measurements, daily stream flow records, and descriptions of stations, for stations where stream flow records are being compiled, are published by the U. S. Geological Survey in their water supply papers. Records secured at the other river stations are not published. Discharge measurements made on artificial channels are not published except where the results are needed to determine total runoff at river stations. In such cases the results are published in the U. S. Geological Survey water supply papers.

The data on rainfall, runoff, and soil moisture collected at Moraine Park is given in full in chapter III of this volume. The data on rainfall intercepted by trees is given in chapter VII.

River or rainfall records secured by the Miami Conservancy District and not published may be obtained from the District at the cost of blue printing.

CHAPTER III.—MORAINE PARK EXPERIMENTS

In February, 1915, it was decided to make a series of field investigations of precipitation, surface runoff, and soil moisture at isolated plats of various characteristics, the object being to obtain data on the conditions under which surface, or flood, runoff takes place. For this purpose four small experimental plats were located in an orchard at Moraine Park, the home of Colonel E. A. Deeds, about five miles south of Dayton. It was recognized, of course, that these plats were too small and too few in number to be representative of the average conditions throughout the Miami Valley. In fact, it was known that the conditions are not typical. The area just south of Dayton consists of deep glacial deposits of sand and gravel, covered with a thin layer of surface soil, in the form of comparatively steep eskers and moraines; while the areas north of Dayton are slightly rolling glaciated areas with deeper surface soil underlaid by materials of various nature and geological age. However, it was thought that if a detailed study could be given to the rainfall and runoff conditions at selected places, by experienced observers, valuable information regarding the laws of runoff could be secured.

For a study of the laws of runoff and the relation of runoff to rainfall small experimental plats possess certain definite advantages over the much larger drainage areas which exist above the stream gaging stations. For instance the slopes of the ground surface within the plats, as well as the character of the soil and surface covering, can be accurately determined without making elaborate and costly surveys. In fact, the plats may be located so that definite comparisons can be secured between the runoff from areas having different surface conditions. Certain questionable features pertaining to the larger areas are practically eliminated in the smaller, such as the absorption of runoff by the soil before it reaches the drains and the amount of runoff contributed by the ground water storage.

While the Moraine Park experiments do not furnish conclusive evidence on all phases of the subject, it is believed that the results are worthy of presentation.

DESCRIPTION OF PLATS

Four plats, each five feet square, are located in open places in the orchard, two on level ground and two on a hillside, the two sets being about a hundred feet apart, and the two plats of each set being about ten feet apart. A standard rain gage was installed near each set. The plats on the hillside were placed where the slope of the ground is about eighteen feet per hundred. One plat on the hillside and one on the level ground were located where the surface covering is a heavy blue grass sod. The other two were located where the sod had been removed leaving the soil bare.

The upper two feet of soil on the hillside is a yellow, sandy loam containing some clay and gravel; the upper two feet where the level plats were established is a similar material except that it contains a larger proportion of gravel. At both places the upper foot contains considerable humus. Of course the soil under the blue grass covering is practically full of roots, some of which extend to depths of 2 feet or more. The material underlying the 2-foot layer of loam, in both cases, is a mixed sand and gravel of glacial origin. On the hillside there is a fairly definite division between the loam and the underlying deposits. On the level ground the proportion of sand and gravel increases more or less uniformly with the depth below the surface until a depth of about two feet is reached. Below this depth the amount of silt and clay present is negligible.

Mechanical analyses of typical samples of the surface soil taken on the level and on the hillside showed that the proportion retained on a quarter inch sieve is about 30 per cent, by weight, for the former and about 7.5 per cent for the latter. The analyses of the portions passing the quarter inch sieve, made by the Bureau of Soils, U. S. Department of Agriculture, gave the following results:

	Percentage by Weight	
	Level	Hillside
Fine gravel, 2 to 1 mm.	3.0	2.6
Coarse sand, 1 to 0.5 mm.	11.8	9.8
Medium sand, 0.5 to 0.25 mm.	12.2	9.0
Fine sand, 0.25 to 0.10 mm.	29.6	28.0
Very fine sand, 0.10 to 0.05 mm.	7.4	8.7
Silt, 0.05 to 0.005 mm.	19.6	24.0
Clay, less than 0.005 mm.	16.4	18.0

The plats were isolated from the adjacent ground by corrugated iron strips set into the ground about eight inches and ex-

tending above the ground about four inches. In setting these strips care was taken not to disturb the ground inside the plats. Concrete was placed around the outside of the corners so as to prevent leakage at the joints. Of course it is quite possible that some water may creep down the inside edges of the iron strips thus slightly increasing the soil percolation.

A galvanized iron tank, eighteen inches in diameter and four feet deep, to catch the surface runoff, was set in the ground just outside the lower corner of each plat, and was connected with the inside of the plat by a joint of three-inch sewer pipe, laid in concrete. A wire screen, to keep out vermin, was fastened over the upper end of each sewer pipe. The tanks were tested and found to be water-tight before being installed; and were tested at intervals after installation, no leaks being found at any time. They were provided with suitable tight fitting covers so that no water except surface runoff from the plats could be caught, and so that the evaporation within the tanks would be reduced as much as possible. The capacity of each tank is equivalent to a runoff of about 3.0 inches depth over the plat with which it is connected.

Some trouble was encountered at times due to leaves stopping up the screens and causing the runoff to spill over the tops of the iron strips. This occurred mostly at the plat on the hillside having the bare soil surface. The screens were later replaced by wire mesh having openings about three-eighths of an inch square, after which more satisfactory records were obtained.

The work of establishing the plats and installing the gages was completed March 4, 1915, and the measurements were begun the following day.

METHODS OF MEASUREMENT

Measurements of rainfall, runoff, and soil moisture have been made more or less regularly since the plats were established. The endeavor has been to secure observations just before and just after each rain, and also to secure measurements of soil moisture once or twice a week between rains, to determine the rates of drying of the soil. Owing to the pressure of other work it has not always been possible to adhere strictly to the above plans. Observations were also discontinued for short intervals during the winter months, as, for instance, during the severe winter of 1917 and 1918. During the first year the soil moisture determinations were made rather irregularly. Some-

times samples were taken to depths of 18 or 24 inches, but more frequently they were only taken to depths of 12 inches. Since March, 1916, however, samples have been taken systematically to depths of 24 inches.

Where precipitation occurred on two or more days between successive readings of the gages it is possible to estimate the daily amounts at Moraine Park from the daily records taken by the U. S. Weather Bureau at Dayton. While such estimates may be considerably in error during summer thunder-storms it is not believed that they are greatly in error at other times. Valuable information regarding intensities of rainfall is also furnished by the graphical automatic records being secured at the Dayton Weather Bureau station. Notes regarding rainfall and runoff conditions were made by the writer at his home in Carrmonte, about two miles north of Moraine Park.

Rainfall measurements were made in the usual manner, that is, using the regular rain gage measuring sticks. The amounts of runoff were determined by measuring distances from the tops of the cans down to the water surfaces, using yard sticks, and reading distances to eighths of an inch. A depth in the can of an eighth of an inch corresponds to a depth over the plat of about 0.009 of an inch.

The amount of moisture in the soil, under the sod and under the bare surface, was determined by taking samples, weighing them, drying, and reweighing. Samples weighing about a kilogram, or about two pounds, were taken at intervals of about six inches in depth down to a depth of about two feet. During the first few months samples were taken close to the plats on the hillside as well as close to those on the level ground. Slightly different results under similar surface coverings were obtained at the two places, the moisture content of the soil on the hillside generally being a little greater than that of the soil on the level ground. This was probably due to the much larger proportion of gravel in the soil at the latter place. Later on samples were taken from beneath the sod and bare soil surfaces at a place on level ground, from 25 to 100 feet southeast of the level plats, where the soil was very similar to that on the hillside.

The samples were placed in paper sacks and dried in the furnace room at Moraine Park. Harvard scales, reading to tenths of a gram, were used in weighing. Weights were tested and adjusted using standard scales of known accuracy. The samples were dried and reweighed until their dry weight became

constant, before they were discarded. When the investigations were begun it was attempted to dry the samples by leaving them in small incubators which could be kept at a constant temperature of about 100° Fahrenheit. It was found, however, that owing to poor air circulation in the incubators it required several weeks to dry the samples thoroughly. They were then placed in the furnace room, directly over the furnace, where they dried out in a few days; or, when the furnace was not being used, they were placed on shelves above a small coal water heater, which was used every morning.

Determinations of the weight per cubic foot of the upper two feet of soil were made December 8, 1919. Samples were taken by boring down with a post hole auger, and were weighed, dried and reweighed in the laboratory at the headquarters office. The cubical contents of the samples were obtained by weighing the amounts of dry sand of known density required to fill the holes from which the samples had been taken.

RESULTS OF OBSERVATIONS

Weight of Soil per Cubic Foot

The data on the weight per cubic foot of the upper two feet of soil is given in table 2. Samples 1 and 4 were taken from beneath the bare surface on the level ground, where the samples for determining the moisture content of the soil have been taken regularly. Samples 2 and 3 were taken from beneath the sod surface on the level ground. Sample 5 was taken from beneath the sod surface near the plats on the hillside.

Table 2.—Determinations of Weight per Cubic Foot of Moraine Park Loam

Sample Number	Volume of Sample	Weight when taken	Weight of Moisture in Sample	Dry Weight of Sample	Weight per cubic foot when taken	Weight per cubic foot when dry	Moisture in Sample
	Cubic feet	Pounds	Pounds	Pounds	Pounds	Pounds	Per cent*
1	0.410	47.1	9.9	37.2	115	91	26.6
2	0.652	81.4	15.4	66.0	125	101	23.3
3	0.710	85.9	13.6	72.3	121	102	18.8
4	0.510	58.6	8.8	49.8	115	98	17.8
5	0.713	86.3	13.1	73.2	121	103	17.9
Average	....	....	....	....	119.4	99.0	20.9

*Based on dry weight.

It will be noticed that there was about 20.9 per cent of moisture in the soil at the time the samples were taken; that the weight per cubic foot of the soil when taken varied from 115 to 125 pounds, averaging 119.4 pounds; and that the weight per cubic foot when dry varied from 91 to 103 pounds, averaging 99.0 pounds. In order to simplify the calculations an average value of 100 pounds has been used for the dry weight in the studies taken up later.

When the samples were taken there was, on the average, about 20.4 pounds or .33 of a cubic foot of water in each cubic foot of soil. While the upper two feet of soil at that time was about as wet as it ever gets under field conditions, the actual volume of the voids was probably a little greater than this. If a value of 2.7 is assumed for the specific gravity of the soil particles, an average value based on several laboratory determinations, the weight of a cubic foot of soil particles would be 169 pounds, the volume of the particles in one cubic foot of soil in place would be 0.59 of a cubic foot and the volume of the voids in one cubic foot would be 0.41 of a cubic foot. Consequently the maximum amount of moisture that could be present in the soil would be 41 per cent by volume or about 25.6 per cent of the dry weight.

Rainfall, Runoff, and Soil Moisture

Table 3 gives the results of all observations of rainfall, runoff, and soil moisture, taken from the time the plats were established up to the end of October, 1919, about four years and eight months in all. Column 1 gives the date of observations. Columns 2 to 5, inclusive, give the moisture content of the soil under the sod covering, expressed as percentages of the dry weight. Column 6 gives the average moisture content of the soil under the sod covering calculated from the data in columns 2 to 5. Columns 7 to 11, inclusive, give corresponding data for the soil under the bare surface. Column 12 gives the observed rainfall. Columns 13 to 15, inclusive, give the data on runoff from the plats having the sod covering. Column 13 gives the runoff from the level plat, column 14 gives the runoff from the plat on the hillside, and column 15 gives the average runoff from the two. Columns 16 to 18, inclusive, give similar runoff data for the plats having the bare soil surface. The maximum and minimum records of soil moisture are set in bold face type so they can be easily located.

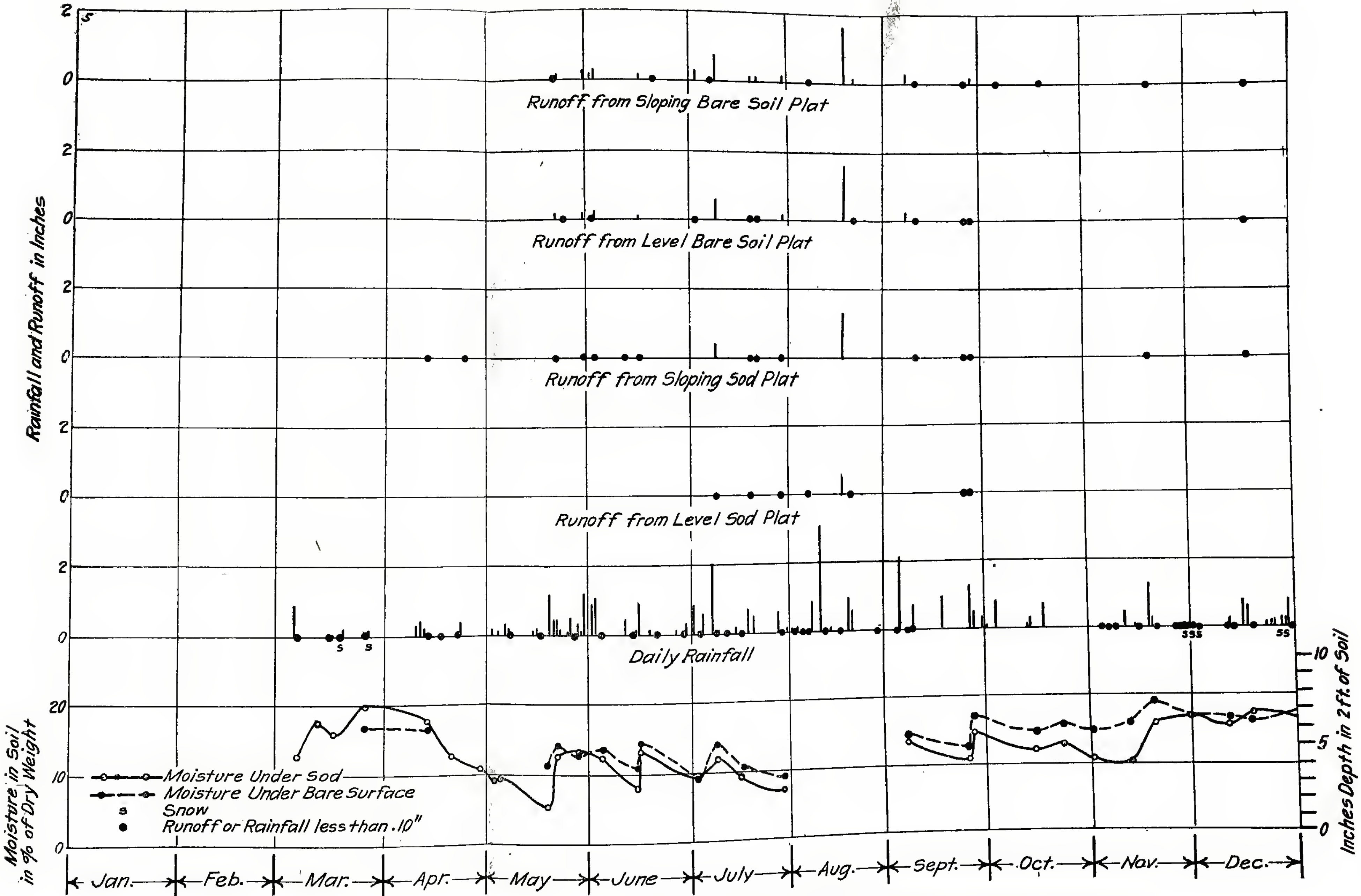

FIG. 4.—RECORDS OF RAINFALL, RUNOFF, AND SOIL MOISTURE SECURED AT MORAINE PARK DURING 1915.

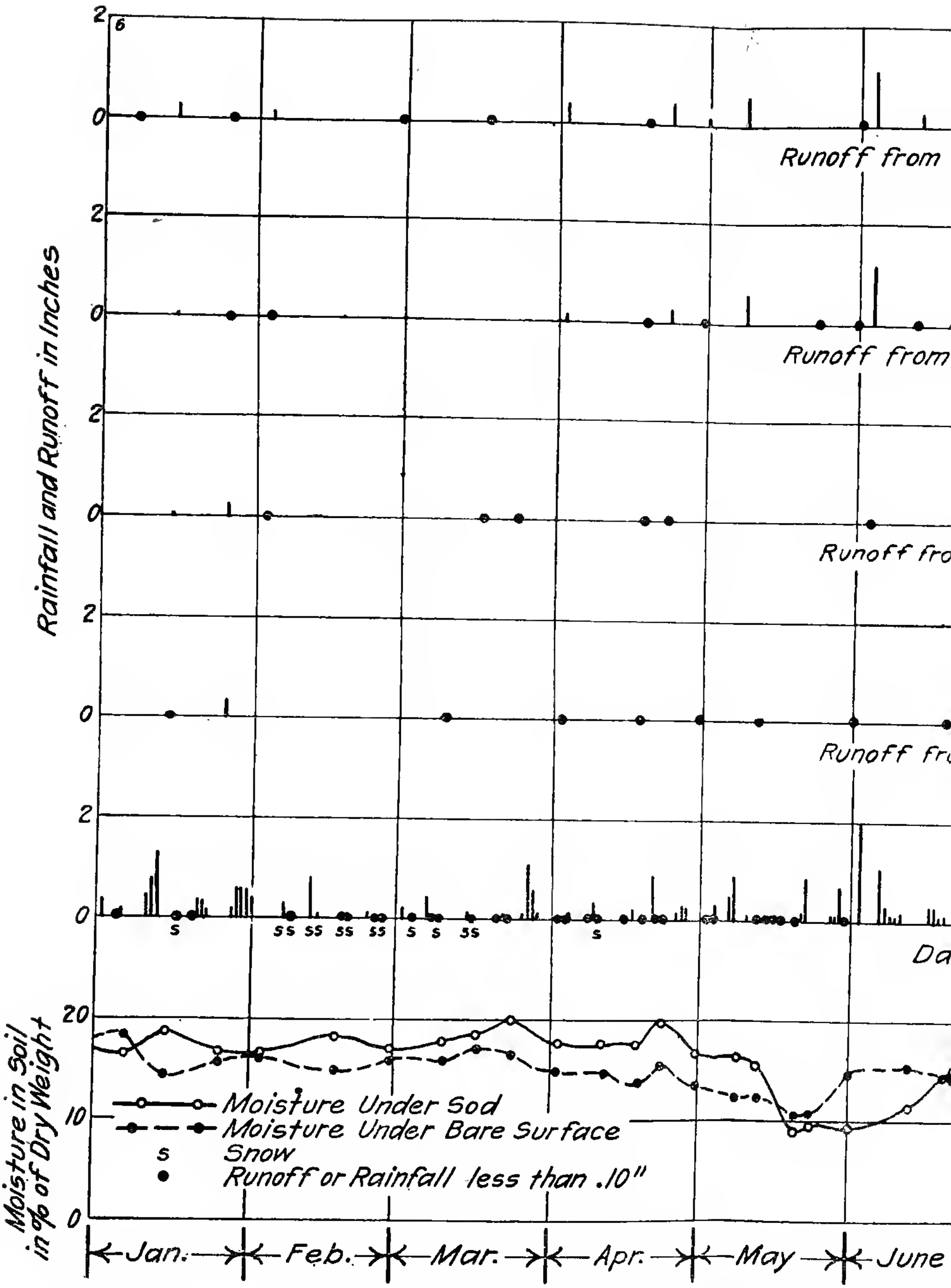

FIG. 5.—RECORDS OF RAINFALL, RUNOFF, AND SO

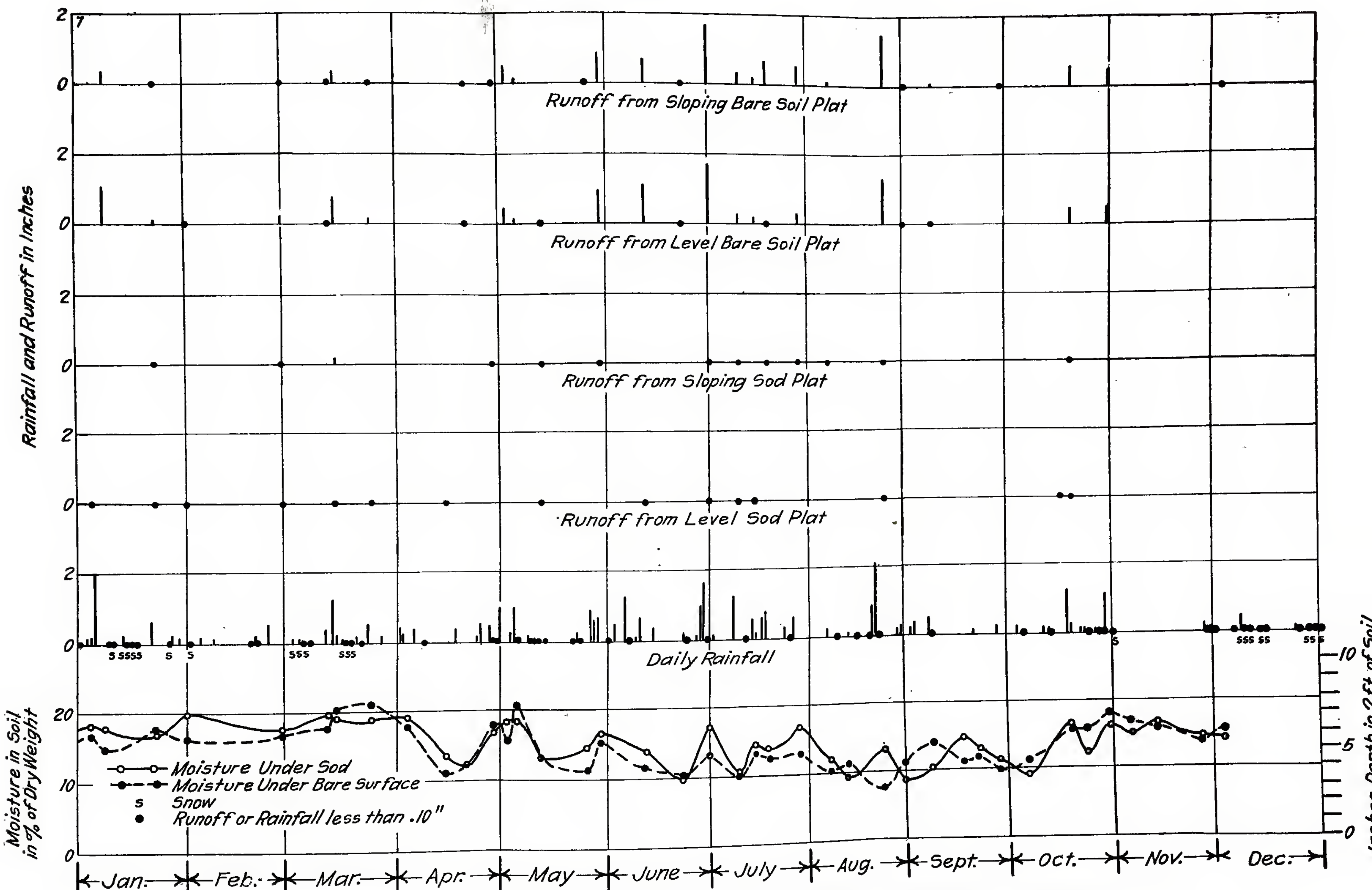

FIG. 6.—RECORDS OF RAINFALL, RUNOFF, AND SOIL MOISTURE SECURED AT MORAINE PARK DURING 1917.

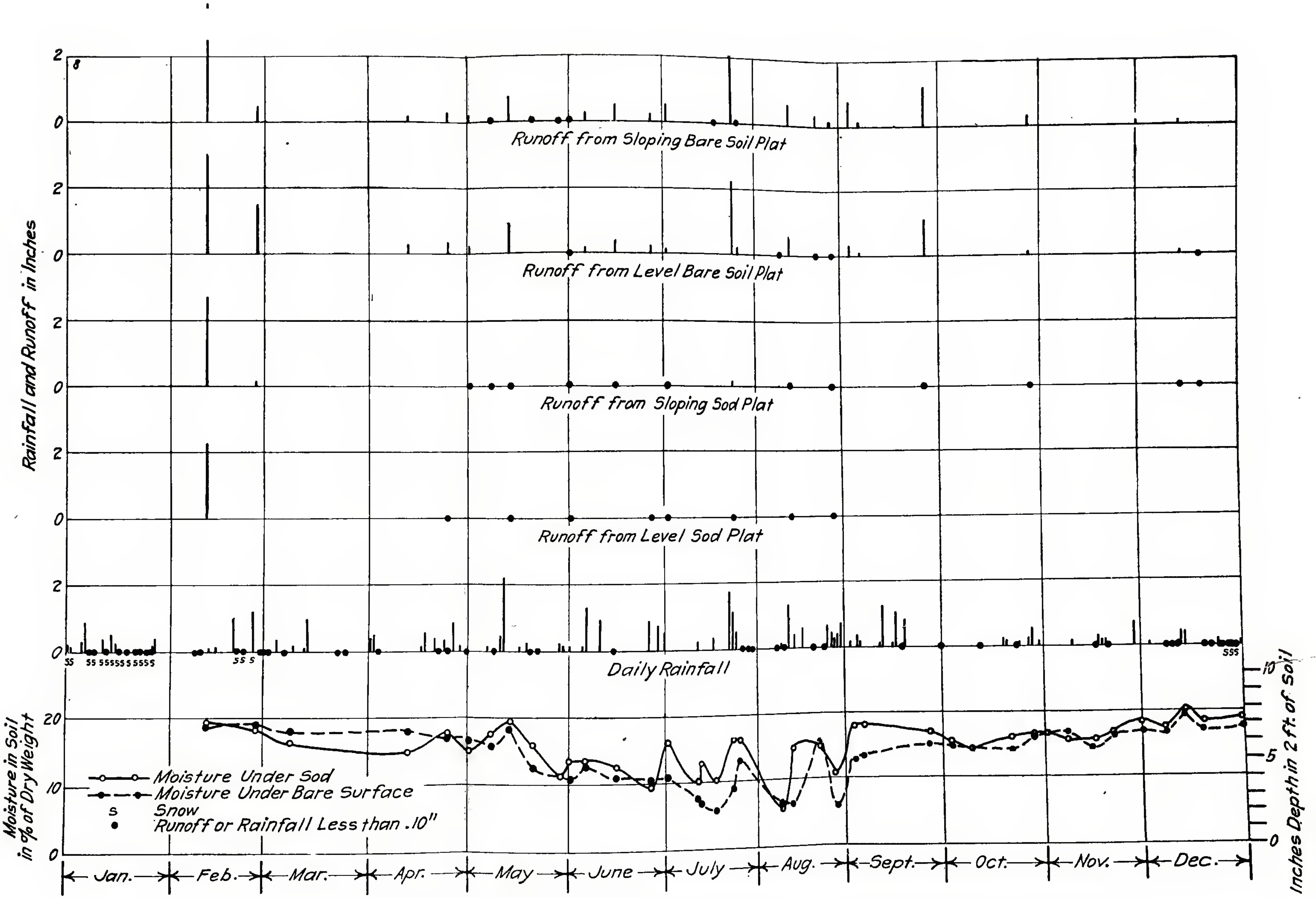

FIG. 7.—RECORDS OF RAINFALL, RUNOFF, AND SOIL MOISTURE SECURED AT MORAINE PARK DURING 1918.

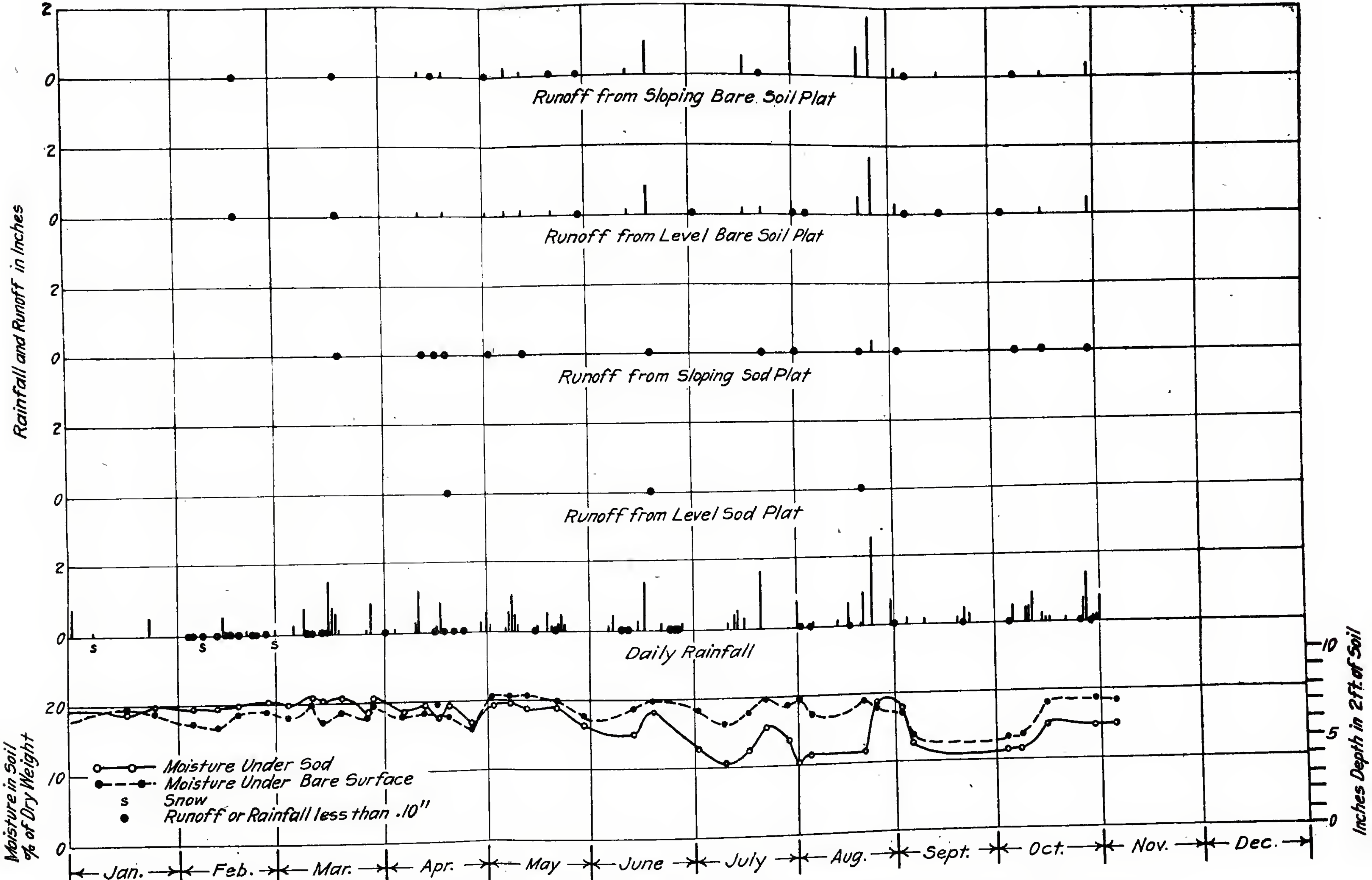

FIG. 8.—RECORDS OF RAINFALL, RUNOFF, AND SOIL MOISTURE SECURED AT MORAINE PARK DURING 1919.

The rainfall records given in column 12 were obtained by averaging the observations at the two rain gages, it being assumed that the differences in the two readings were due to instrumental and observational errors rather than to actual differences in precipitation at the two places. The differences were small in all cases, seldom exceeding 0.05 of an inch, except in cases where the gages had not been read for some time or where the precipitation had occurred as snow.

The data given in table 3 is shown graphically in figures 4 to 8, inclusive, each calendar year's records being shown on a separate sheet. The rainfall and runoff records, in inches depth, are platted as vertical bars in the upper parts of the diagrams, whenever the depth amounted to or exceeded a tenth of an inch. The occurrences of amounts less than a tenth of an inch are indicated by small circles. In platting the rainfall the amounts given in column 12 have been distributed over the days on which the precipitation occurred, as shown by the Dayton U. S. Weather Bureau records. This distribution was made on the assumption that the ratio of the rainfall on a given day to the total precipitation for a period including the given day was the same at both locations. While this assumption may be considerably in error during summer thunder-showers, as previously mentioned, it probably is not seriously incorrect during the more steady rains of the winter and spring. At any rate it gives the reader an idea of the general distribution of the rainfall and of the dates on which the greater part of the runoff occurred. Whenever the precipitation occurred in the form of snow a small "s" has been placed below the circle or line representing the precipitation.

Runoff records for each plat are shown, but the averages for the different types of surface covering, given in columns 15 and 18 of table 3, are not platted. The actual runoff records, given in table 3, are platted on the dates on which the observations were made. No attempt has been made to distribute the amounts or to plat them on the days on which they must have occurred.

The averages of the soil moisture determinations for the different types of surface covering, given in columns 6 and 11 of table 3, are shown in the lower parts of the diagrams. The percentages are platted as points, and the points are connected by lines. The points representing the moisture under the sod are connected by continuous lines, and those representing the

Table 3.—Results of Rainfall, Runoff, and Soil Absorption Experiments at Moraine Park

Date	Moisture in Soil, in per cent of dry weight										Rainfall in Inches	Runoff, in inches depth					
	Under Sod Cover, depth of					Bare Soil, depth of						Sod			Bare Soil		
	6"	12"	18"	24"	Average	6"	12"	18"	24"	Average		Level	Sloping	Average	Level	Sloping	Average
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1915																	
3- 4												Gages Established					
3- 5											.95	0	0	0	0	0	0
3- 6		*12.8			12.8						.06	0	0	0	0	0	0
3- 8											T	0	0	0	0	0	0
3-12	14.6	15.0	18.0	23.0	17.6						0	0	0	0	0	0	0
3-16	*16.0	*15.6	*23.7	*24.9	15.8						.03	0	0	0	0	0	0
3-19											.27	0	0	0	0	0	0
3-20											T	0	0	0	0	0	0
3-22											T	0	0	0	0	0	0
3-25	16.6	18.0	21.2	23.6	19.8	15.0	15.8	19.3	17.6	16.9	.01	0	0	0	0	0	0
4-12	15.3	17.0	18.5	20.5	17.8	14.7	14.2	20.7		16.5	1.05	0	.01	.01	0	0	0
4-16											.03	0	0	0	0	0	0
4-19	*11.0	*13.2	*14.4		12.9						0	0	0	0	0	0	0
4-23											.47	0	.02	.01	0	0	0
4-28	* 9.2	*10.8	*12.3		10.8						0	0	0	0	0	0	0
5- 3	* 6.0	* 9.1	*12.1		9.1						.18	0	0	0	0	0	0
5- 5	* 6.3	* 8.7	*13.3		9.4						.09	0	0	0	0	0	0
5- 7											.46	T	0	T	T	T	T
5-11											.04	0	0	0	0	0	0
5-15											.09	0	0	0	0	T	T
5-19	4.7	5.7			5.2	10.7	11.5			11.1	.24	0	0	0	0	0	0
5-20											1.15	0	0	0	0	0	0
5-21											.44	T	0	T	0	.08	.04
5-22	14.2	11.0			12.6	*14.6	*13.5			14.0	.43	0	.08	.04	.11	.19	.15
5-24											.21	0	0	0	.01	0	.01

*See descriptive notes.

Table 3.—*Continued*

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
5–26											.63	0	0	0	0	0	0
5–28	13.3	13.2			13.2	*12.6	*13.2			12.9	.40	0	0	0	0	0	0
5–29											.16	0	0	0	0	0	0
5–30											1.22	0	.02	.01	.18	* .19	.18
6– 1											.87	T	0	T	.01	.20	.10
6– 2											1.14	0	.04	.02	.18	.32	.25
6– 4	*12.5	*11.8	12.5	12.3	12.3	11.9	13.6	14.3	14.6	13.6	.01	0	0	0	0	0	0
6– 7											T	0	0	0	0	0	0
6–11											.51	0	.02	.01	0	0	0
6–14	7.7	8.4			8.0	10.7	10.8			10.8	.20	0	0	0	0	0	0
6–15	14.5	12.1			13.3	14.2	14.7			14.4	1.10	0	.02	.01	.13	.13	.13
6–19											.14	0	0	0	0	.01	.01
6–22											.06	0	0	0	0	0	0
6–27											.07	0	0	0	0	0	0
6–30											.36	0	0	0	0	0	0
7– 2	12.7	6.3			9.5	10.6	8.2			9.4	.86	0	0	0	.04	.26	.15
7– 3											.06	0	0	0	0	0	0
7– 6											.58	0	0	0	0	.10	.05
7– 8	11.2	12.6			11.9	14.1	13.9			14.0	2.11	.06	.41	.24	.60	.79	.70
7–16	9.7	8.6			9.2	10.4	11.4			10.9	.29	0	0	0	0	0	0
7–19											.80	.04	.10	.07	.02	.17	.10
7–21											.44	0	.01	.01	.05	.12	.08
7–29	6.1	8.0			7.0	7.7	10.3			9.0	.66	.07	.08	.08	.10	* .18	.14
8– 7											.46	.01	0	.01	0	.01	.01
8–18											4.22	.61	1.33	.97	1.61	1.73	1.67
8–21											1.46	.03	0	.02	.02	.12	.07
9– 7	14.4	12.0			13.2	13.9	14.7			14.3	2.22	0	0	0	* .24	* .39	.32
9–10											.75	0	.02	.01	.01	.01	.01
9–25	10.4	10.8			10.6	12.2	12.9			12.6	1.04	.04	.04	.04	.05	.07	.06
9–27	15.8	13.3			14.6	17.1	16.8			17.0	1.82	.01	.01	.01	.01	.18	.10
10– 5											1.30	0	0	0	0	.05	.02
10–15	12.7	11.3			12.0	15.0	14.2			14.6	0.37	0	0	0	0	0	0
10–18											.78	0	0	0	0	.10	.05

*See descriptive notes.

Table 3.—*Continued*

Date	Moisture in Soil, in per cent of dry weight										Rainfall in Inches	Runoff, in inches depth					
	Under Sod Cover, depth of					Bare Soil, depth of						Sod			Bare Soil		
	6″	12″	18″	24″	Average	6″	12″	18″	24″	Average		Level	Sloping	Average	Level	Sloping	Average
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1915																	
10–23	13.0	12.4	......	......	12.7	15.8	15.4	......	......	15.6	.03	0	0	0	0	0	0
11– 1	9.6	10.5	10.3	12.5	10.7	12.4	14.5	18.5	13.3	14.7	0	0	0	0	0	0	0
11–12	8.8	9.5	12.1	......	10.1	13.7	17.5	16.8	......	16.0	.58	0	0	0	0	0	0
11–19	16.6	14.9	......	......	15.8	18.3	19.7	......	......	19.0	1.64	0	01	01	0	.01	01
*11–30	15.9	16.2	19.3	......	17.1	15.9	16.8	19.0	......	17.2	.18	0	0	0	0	0	0
12–11	15.6	15.5	15.6	......	15.6	15.5	15.7	18.9	......	16.7	* .15	0	0	0	0	0	0
12–18	17.1	16.1	18.8	......	17.3	15.6	15.8	17.6	......	16.3	1.75	0	.03	.02	.02	.03	.03
1916																	
1– 6	18.0	15.1	16.1	......	16.4	16.8	18.7	19.7	......	*18.4	2.50	0	0	0	0	.01	.01
1–14	19.3	20.3	16.6	......	18.7	14.9	14.1	14.2	......	*14.4	2.52	.03	.15	.09	.11	.34	.22
1–25	16.0	16.6	......	18.0	16.9	18.0	14.5	......	14.7	15.7	.92	* .38	* .36	.37	.01	.04	.02
2– 2	16.4	15.6	......	17.7	16.6	16.5	15.3	......	16.8	*16.2	2.39	0	.01	.01	.01	.09	.05
2–17	17.9	16.2	20.4	......	*18.2	14.4	15.3	14.9	......	*14.9	1.18	0	0	0	0	0	0
2–28	17.3	17.9	16.2	16.5	*17.0	12.7	14.9	16.8	19.1	*15.9	.10	0	0	0	0	.01	.01
* 3– 9	15.7	16.2	19.3	20.0	17.8	15.2	16.6	18.1	13.7	15.9	.68	.01	0	.01	0	0	0
3–16	19.7	19.7	15.9	18.2	*18.4	19.0	16.0	14.9	18.0	*17.0	* .19	0	.01	.01	0	.02	.01
3–23	19.2	19.6	19.3	21.6	19.9	20.0	16.5	14.3	16.2	16.7	.20	0	.01	.01	0	0	0
4– 1	17.5	15.5	17.7	19.8	17.6	14.6	13.3	15.5	16.0	14.8	2.06	.02	0	.01	.18	.37	.28
4–10	19.1	16.0	17.5	18.5	17.8	15.3	13.6	15.2	14.9	14.8	.65	0	0	0	0	0	0
4–17	17.8	17.9	16.4	18.7	17.7	13.4	12.3	13.4	15.6	13.7	.28	.01	.01	.01	.01	.01	.01
4–22	19.7	19.7	19.3	20.3	19.8	16.5	13.8	14.3	16.5	15.3	1.08	0	.01	.01	.23	.37	.30
4–29	19.1	18.4	17.8	12.0	16.8	14.2	12.0	13.8	13.6	13.4	.76	.02	0	.01	.07	.08	.08
5– 8	15.4	16.3	16.9	17.5	16.5	13.0	11.7	12.1	12.6	12.3	1.81	0	0	0	.60	.58	.59
5–12	13.6	16.1	15.8	16.5	15.5	11.7	10.8	13.8	12.6	12.2	.10	.01	0	.01	*0	*0	0
5–20	6.4	7.4	10.5	11.7	9.0	9.2	9.3	11.1	12.0	10.4	.10	0	0	0	0	0	0

*See descriptive notes.

Table 3.—*Continued*

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1916																	
5–23	10.7	7.1	9.5	11.6	9.7	12.1	9.5	10.0	11.0	10.6	1.05	0	0	0	.01	0	.01
5–31	11.1	6.1	9.5	10.8	9.4	14.4	14.4	14.7	14.9	14.6	1.07	.02	0	.01	.01	.03	.02
6– 3	......	......	......	......	......	......	......	......	......	......	1.99	0	.04	.02	1.19	*1.11	1.15
6–12	12.2	10.8	11.7	12.3	11.8	16.3	16.5	15.6	12.4	15.2	1.89	0	0	0	.09	.20	.14
6–19	16.5	12.7	14.2	14.6	14.5	14.8	13.9	15.1	14.5	14.6	.96	* .04	*0	.02	.04	.11	.08
6–21	14.8	13 9	15.0	15.5	14.8	16.0	13.6	14.6	13.8	14.5	.82	0	0	0	.05	.22	.14
7– 5	4.4	7.0	01.5	11.3	8.3	6.8	7.9	10.0	11.4	9.0	.15	0	0	0	*0	*0	0
7–24	3.7	4.9	10.1	13.6	8.1	2.9	2.9	10.8	3.1	4.9	.32	.01	0	.01	0	0	0
8– 2	3.5	4.7	4.5	6.1	4.7	2.1	2.8	3.5	3.9	3.1	.50	.08	.02	.05	.08	.16	.12
8– 7	14.9	12.8	13.5	12.4	13.4	11.9	5.6	5.0	4.9	6.9	3.63	*0	* .24	.12	1.55	* .97	1.26
8– 8	16.5	15.2	14.3	13.4	14.9	18.0	16.6	14.1	8.3	14.2	.93	.02	0	.01	0	.04	.02
8–21	9.0	9.2	11.0	11.8	10.2	5.2	5.0	4.0	4.7	4.7	.12	0	0	0	0	0	0
8–28	8.0	8.2	10.3	10.6	9.3	3.1	3.3	4.1	4.4	3.7	.80	0	.01	.01	0	.02	.01
9– 6	13.9	15.9	15.3	16.5	15.4	15.1	5.4	6.8	8.7	9.0	4.32	0	.05	.02	*1.90	1.66	1.78
9– 9	16.8	17.3	14.7	15.8	16.2	12.6	10.7	6.5	*	9.9	.49	*0	*0	0	.05	.15	.10
9–22	6.2	7.4	9.8	11.4	8.7	9.1	8.4	6.5	5.4	7.4	.06	*0	*0	0	*0	*0	0
9–29	16.2	17.1	19.7	12.6	16.4	14.3	5.1	13.2	12.6	11.3	1.68	0	0	0	0	0	0
10– 6	10.5	7.5	9.5	9.8	9.3	8.8	8.1	8.2	6.4	7.9	.01	0	0	0	0	0	0
10–13	12.2	11.9	10.2	11.5	11.4	9.8	8.9	9.5	8.5	9.2	.41	.02	0	.01	.01	0	.01
10–23	15.6	17.0	13.8	13.9	15.1	13.8	10.1	9.3	8.5	10.4	1.31	0	0	0	0	0	0
11–10	14.6	14.7	14.7	16.1	15.0	14.4	10.1	9.9	8.7	10.8	.42	0	0	0	0	0	0
11–20	11.0	10.3	11.9	11.9	11.3	13.6	12.4	11.2	9.5	11.7	.23	*0	*0	0	0	0	0
11–24	16.6	16.4	16.3	18.1	16.9	17.7	15.7	14.2	12.8	15.1	.84	0	.01	.01	.01	.01	.01
12– 4	......	......	......	......	*	15.5	13.9	13.8	10.5	13.4	.55	0	0	0	.09	.01	.05
12–27	19.1	17.4	15.2	17.8	17.4	16.8	15.2	15.4	14.0	15.4	1.94	* .72	* .40	.56	* .40	* .12	.26
1917																	
1– 4	20.4	18.7	17.0	17.3	18.4	19.3	15.4	15.6	17.0	16.8	.27	.02	0	.01	0	0	0
1– 8	17.1	16.0	18.5	20.0	17.9	16.3	13.8	14.5	15.9	*15.1	2.04	*0	*0	0	1.04	.41	.72
1–22	18.3	16.8	15.7	17 2	17.0	19.9	18.0	16.6	15.9	*17.6	1.05	* .04	* .01	.02	* .10	* .05	.08
1–31	19.7	20.0	19.4	20.4	19.9	17.5	15.2	15.7	16.7	*16.3	.32	.01	0	.01	.05	0	.02
2–27	19.6	18.2	17.0	15.6	17.6	21.8	17.2	14.3	14.0	16.8	1.08	.01	.04	.02	.22	.06	.14
3–12	18.6	19.6	19.9	20.9	19.8	17.9	18.9	18.3	16.3	17.8	.70	0	0	0	.01	.02	.02

*See descriptive notes.

Table 3.—*Continued*

Date	Moisture in Soil, in per cent of dry weight: Under Sod Cover, depth of 6″	12″	18″	24″	Average	Bare Soil, depth of 6″	12″	18″	24″	Average	Rainfall in Inches	Runoff, in inches depth: Sod: Level	Sloping	Average	Bare Soil: Level	Sloping	Average
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1917																	
3–14	16.2	18.9	20.4	20.4	19.0	19.3	20.6	19.9	21.3	20.3	1.44	.01	.18	.10	.79	.38	.58
3–24	16.7	19.2	19.5	19.7	18.8	19.7	21.6	21.6	21.5	21.1	.82	.01	0	.01	.16	.08	.12
4– 3	19.4	23.3	15.9	17.6	19.0	18.2	16.0	16.4	20.7	17.8	.96	0	0	0	0	0	0
4–14	13.9	12.6	13.8	14.3	13.6	12.0	13.0	14.5	5.0	11.1	.48	.01	0	0	0	0	0
4–20	13.4	12.1	14.2	14.4	13.5	14.3	14.2	14.7	11.6	13.7	.40	0	0	0	.01	.02	.02
4–28	15.6	17.0	18.2	17.4	17.0	20.2	18.0	15.7	16.5	17.6	1.04	0	.01	.01	0	.02	.01
5– 2	17.5	18.5	18.9	19.0	18.5	16.8	14.7	15.6	15.3	15.6	1.00	0	0	0	.46	.47	.46
5– 5	16.5	18.1	20.9	*29.3	18.5	20.2	20.4	21.8	*40.7	20.8	1.23	0	0	0	.09	.11	.10
5–12	14.4	11.7	13.8	13.1	13.2	11.5	12.9	14.0	14.3	13.2	.15	.01	.01	.01	.05	0	.02
5–25	20.8	11.1	12.5	14.3	14.7	12.1	11.0	10.7	11.7	11.4	.33	*0	*0	0	*0	* .01	.01
5–29	15.3	17.1	18.2	16.7	16.8	17.0	14.3	14.7	15.0	15.2	2.28	0	.01	.01	.97	.83	.90
6–11	13.9	13.2	16.8	12.0	14.0	11.4	12.1	12.5	10.9	11.7	2.77	.01	0	.01	1.08	.73	.90
6–22	8.5	8.6	10.2	12.4	9.9	7.6	10.6	11.5	11.7	10.4	0.44	0	0	0	.04	.08	.06
6–30	16.4	18.0	17.7	16.8	17.2	13.5	15.1	12.6	12.1	13.3	2.90	.02	.03	.02	*1.73	1.66	1.70
7– 9	11.9	11.4	11.0	8.1	10.6	11.9	9.9	9.8	9.9	10.4	1.36	.01	.01	.01	.25	.34	.30
7–14	14.3	13.9	14.4	15.4	14.5	13.3	12.7	13.6	12.7	13.1	.84	.02	0	.01	.21	* .21	.21
7–18	14.8	12.9	14.0	14.1	14.0	13.4	12.5	12.9	11.1	12.5	1.43	0	.01	.01	.01	.79	.40
7–28	16.3	17.6	18.5	15.4	17.0	12.2	12.6	13.2	13.9	13.0	.96	0	.02	.01	.25	.60	.42
8– 7	8.9	12.2	13.2	13.1	11.8	10.8	9.8	10.2	10.3	10.3	.37	0	.01	.01	0	.11	.06
8–13	6.8	9.4	10.9	10.5	9.4	8.5	10.6	12.1	14.4	11.4	.19	0	0	0	0	0	0
8–25	15.3	16.7	10.7	9.6	13.1	10.0	6.1	6.7	7.1	7.5	3.04	.03	.01	.02	1.35	1.52	1.44
8–31	9.7	8.2	8.5	8.5	8.7	12.3	13.5	11.6	7.5	11.2	.46	0	0	0	.01	.02	.02
9– 8	13.0	12.1	7.5	9.3	10.5	13.4	14.2	14.7	14.0	14.1	1.15	0	0	0	.09	.10	.10
9–17	12.5	12.8	18.4	15.0	14.7	10.3	12.0	11.7	11.7	11.4	0	0	0	0	0	0	0
9–22	12.9	14.4	13.1	11.7	13.0	12.6	12.9	11.4	11.0	12.0	.16	0	0	0	0	0	0

*See descriptive notes.

Table 3.—*Continued*

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1917																	
9–28	8.3	11.1	11.9	14.4	11.4	9.5	9.5	11.1	10.5	10.1	.22	0	0	0	0	.01	.01
10– 6	6.0	8.0	10.2	12.5	9.2	9.5	11.8	12.0	11.1	11.1	.19	0	0	0	0	0	0
10–16	......	......	......	......	......	......	......	......	......	......	.46	.02	0	.01	0	0	0
10–19	18.3	23.2	10.9	12.5	16.2	17.7	18.1	15.7	12.6	16.0	1.56	0	.01	.01	.49	.59	.54
10–23	17.8	11.6	9.6	10.2	12.3	17.1	17.8	16.0	13.3	16.0	.28	0	0	0	0	0	0
10–30	18.3	17.4	14.0	15.9	16.4	16.8	19.7	19.0	17.2	18.2	1.40	0	0	0	.59	.51	.55
11– 5	16.8	16.3	13.5	13.8	15.1	18.4	19.5	16.7	14.2	17.2	02	0	0	0	0	0	0
11–13	17.6	23.0	12.9	12.9	16.6	16.0	16.4	17.0	15.0	16.1	T	0	0	0	0	0	0
11–26	15.1	14.0	13.4	15.9	14.6	10.8	15.1	15.8	14.3	14.0	.03	0	0	0	0	0	0
* 12– 3	17.0	13.9	12.4	13.8	14.3	14.2	17.2	16.4	14.5	15.6	.30	0	0	0	0	.01	.01
1918																	
* 2–11	24.8	20.9	16.5	15.7	19.5	21.8	20.2	18.5	15.5	19.0	*5.26	*2.29	*2.74	2.52	*3.05	*2.56	2.80
2–26	18.7	21.0	18.4	15.9	18.5	18.6	21.8	21.0	14.3	18.9	2.54	0	.16	.08	1.47	.37*	.92
3– 8	18.6	16.0	14.4	17.5	16.6	18.5	19.0	18.7	16.1	18.1	.65	0	0	0	0	0	0
4–12	18.5	14.6	12.9	13.8	15.0	17.6	16.4	18.3	20.0	18.1	2.57	0	0	0	.26	.15	.20
4–24	17.8	18.0	17.0	17.3	17.5	18.3	18.0	16.6	15.6	17.1	1.50	.01	0	.01	.32	.27	.30
5– 1	17.5	13.7	14.5	15.5	15.2	16.2	17.9	16.7	16.1	16.7	1.05	0	.01	.01	.31	.21	.26
5– 8	24.2	15.9	16.6	14.8	17.7	14.0	20.1	14.5	14.5	15.8	.19	0	.01	.01	0	.01	.01
5–14	19.3	19.1	19.6	18.9	19.2	19.5	18.5	18.6	17.1	18.4	2.77	.02	.01	.02	.95	* .75	.85
5–21	13.9	15.2	17.6	16.7	15.8	12.5	11.3	12.3	13.3	12.4	.38	0	0	0	0	.01	.01
5–29	10.9	11.4	11.3	11.7	11.3	11.7	11.1	10.6	11.5	11.2	.29	0	0	0	0	.04	.02
6– 1	13.8	13.9	13.3	13.0	13.5	11.0	10.6	10.4	11.4	10.8	.23	.01	.01	.01	.01	.04	.02
6– 6	15.0	12.9	13.9	12.5	13.6	15.4	11.4	10.9	12.3	12.5	1.43	0	0	0	.23	.33	.28
6–15	14.0	13.0	11.8	11.4	12.6	11.6	10.9	10.9	10.8	11.0	1.05	0	.01	.01	.47	.52	.50
* 6–26	11.1	7.7	8.5	11.2	9.6	12.2	8.9	9.7	10.8	10.4	.94	.02	0	.01	.21	.21	.21
7– 1	15.3	18.3	15.9	15.6	16.3	14.1	12.6	8.3	8.3	10.8	1.30	0	.01	.01	.18	.57	.38
7–11	9.1	10.6	8.8	12.1	10.2	5.9	7.4	8.7	8.8	7.7	0	0	0	0	0	0	0
7–12	10.6	13.8	13.6	12.9	12.7	5.3	6.4	7.4	8.5	6.9	.22	0	0	0	0	0	0
7–17	8.8	9.4	11.8	11.3	10.3	6.8	4.4	6.1	*	5.8	.37	0	0	0	0	01	.01
7–23	16.0	17.2	16.2	16.1	16.4	13.0	6.1	6.7	10.3	9.0	3.11	.03	.11	.07	2.23	2.20	2.22
7–25	15.1	16.9	16.7	15.8	16.1	16.2	12.7	10.7	13.2	13.2	.57	0	0	0	.18	* .04	.11
8– 9	6.1	5.5	5.5	6.1	5.8	4.5	6.8	6.9	7.9	6.5	.27	0	0	0	.01	0	.01

*See descriptive notes.

Table 3.—*Continued*

Date	Moisture in Soil, in per cent of dry weight										Rainfall in Inches	Runoff, in inches depth					
	Under Sod Cover, depth of					Bare Soil, depth of						Sod			Bare Soil		
	6"	12"	18"	24"	Average	6"	12"	18"	24"	Average		Level	Sloping	Average	Level	Sloping	Average
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1918																	
8–13	12.2	15.5	16.0	14.5	14.6	7.9	6.3	5.4	5.6	6.3	1.24	.02	.02	.02	.61	.71	.66
8–23	*	14.5	16.3	14.3	15.0	15.2	16.3	16.5	15.3	15.8	1.06	0	0	0	.04	.33	.18
8–28	14.0	12.3	9.0	8.2	10.9	*	*	5.6	6.3	6.0	1.54	.01	.01	.01	.01	.12	.06
9– 3	15.3	19.5	19.6	17.8	18.0	12.3	13.3	14.4	10.9	12.7	1.39	0	0	0	.37	.78	.58
9– 6	15.9	17.8	19.6	19.3	18.1	13.5	15.8	13.8	10.9	13.5	.62	0	0	0	.07	.12	.10
9–26	15.4	16.1	18.6	17.9	17.0	13.9	16.9	16.1	13.9	15.2	3.54	0	.01	.01	1.17	1.24	1.20
10– 3	13.6	13.4	17.3	18.3	15.6	14.3	14.8	15.6	15.8	15.1	.01	0	0	0	0	0	0
10– 9	10.2	12.4	17.5	17.6	14.4	13.7	15.7	14.9	13.7	14.5	.10	0	0	0	0	0	0
10–21	12.5	15.5	18.4	17.4	16.0	14.5	15.2	14.6	13.0	14.3	.49	0	0	0	0	0	0
10–28	16.7	16.5	17.2	16.5	16.7	17.0	17.3	15.4	14.9	16.1	.99	0	.01	.01	.13	.30	.22
11– 1	15.8	15.7	17 8	17.2	16.6	16.4	17.9	16.9	15.4	16.7	.18	0	0	0	0	0	0
11– 7	14.5	15.3	17.0	16.7	15.9	16.1	17.0	16.7	15.3	16.3	0	0	0	0	0	0	0
11–15	14.4	14.7	16.6	16.2	15.5	12.7	15.4	15.3	14.2	14.4	.20	0	0	0	0	0	0
11–21	17.5	16.4	17.3	16.5	16.9	16.0	18.4	17.0	14.8	16.6	.89	0	0	0	0	0	0
11–30	17.6	17.7	19.6	17.8	18.2	17.3	18.3	16.9	15.3	17.0	.73	0	0	0	0	0	0
12– 7	15.7	17.8	18.1	18.2	17.4	15.8	18.1	16.6	17.0	16.9	.12	0	0	0	0	.13	.16
12–13	18.8	20.4	20.4	20.2	20.0	19.6	21.4	18.8	17.3	19.3	1.59	0	0	0	0	0	0
12–19	17.7	17.7	19.9	18.1	18.4	18.1	19.2	17.3	15.5	17.5	.44	0	.01	.01	.07	.23	.15
12–31	19.4	19.2	19.3	18.3	19.0	19.9	18.4	16.3	15.6	17.6	.62	0	.01	.01	.01	0	.01
1919												0	0	0	0	0	0
1–16	20.0	18.5	18.3	17.7	18.6	21.1	19.6	18.5	18.0	19.3	.85	0	0	0	0	0	0
1–24	17.6	18.3	23.2	20.3	19.8	21.3	19.7	17.5	16.6	18.8	.47	0	0	0	0	0	0
2– 4	17.3	18.1	22.0	20.0	19.3	18.1	18.6	16.8	15.7	17.3	.06	0	0	0	0	0	0
2–11	15.7	19.1	21.4	20.5	19.2	17.9	16.6	16.9	15.5	16.7	.02	0	0	0	0	0	0
2–17	17.6	18.8	22.4	20.3	19.8	20.8	19.4	17.4	16.2	18.4	.68	0	0	0	.01	.01	.01

*See descriptive notes.

Table 3.—*Continued*

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1919																	
2–25	17.5	20.1	22.5	21.0	20.3	20.0	20.2	18.5	16.4	18.8	.26	0	0	0	0	0	0
3–3	16.8	17.8	22.8	22.1	19.9	18.0	18.6	18.8	16.4	18.0	.09	0	0	0	0	0	0
3–10	18.2	19.7	22.8	23.4	21.0	19.0	21.5	20.0	17.8	19.6	1.09	0	0	0	0	0	0
3–13	18.4	18.4	22.1	22.5	20.4	17.6	19.4	16.7	15.1	17.2	.04	0	0	0	0	0	0
3–18	19.6	20.3	21.4	21.1	20.6	18.8	20.5	18.3	16.2	18.4	2.97	0	.03	.02	.04	.07	.06
3–26	17.1	18.1	19.9	19.3	18.6	16.1	19.0	18.2	17.5	17.7	.10	0	0	0	0	0	0
3–27	18.1	21.6	22.6	20.3	20.6	19.2	20.3	20.1	17.4	19.2	.85	0	0	0	0	0	0
4–5	20.0	18.6	18.1	17.9	18.6	18.5	19.3	17.4	16.7	18.0	.09	0	0	0	0	0	0
4–11	21.5	21.1	18.5	17.3	19.4	19.4	20.4	17.5	16.0	18.3	1.53	0	.03	.02	.13	.16	.14
4–15	16.9	20.6	16.3	17.0	17.7	21.7	20.1	18.7	17.9	19.6	.30	0	.01	.01	0	.01	.01
4–18	21.1	20.5	18.4	17.3	19.3	16.0	20.0	18.0	17.1	17.8	1.02	.01	.01	.01	.13	.14	.14
4–25	18.8	17.9	15.0	15.3	16.8	17.5	17.2	15.3	14.1	16.0	.12	0	0	0	0	0	0
5–1	21.0	20.7	18.6	17.0	19.3	19.5	20.2	21.9	20.6	20.6	1.06	0	.01	.01	.08	.08	.08
5–7	21.3	21.1	19.2	17.0	19.6	19.6	20.5	21.6	20.5	20.6	.73	0	0	0	.17	.26	22
5–12	20.5	19.7	17.7	17.3	18.8	20.7	21.6	21.1	19.7	20.8	1.75	0	.02	.01	.10	.12	.11
5–21	20.6	20.1	17.6	16.9	18.8	20.0	20.8	20.3	18.3	19.8	.84	0	0	0	.12	.02	.07
5–29	17.1	17.2	15.6	15.2	16.3	16.3	17.9	19.3	16.8	17.6	.80	0	0	0	.04	.05	.04
6–12	15.0	15.2	14.7	14.8	14.9	17.2	19.5	18.9	17.7	18.3	.70	0	0	0	.09	.14	.12
6–18	19.9	19.1	16.9	16.3	18.0	17.7	21.1	19.5	19.8	19.5	1.73	.01	.06	.04	.84	.97	.90
7–1	12.2	14.0	13.8	14.1	13.5	17.1	18.9	19.6	17.5	18.3	.38	0	0	0	.01	0	.01
7–9	7.1	10.3	11.9	13.2	10.6	14.5	16.2	17.6	16.4	16.2	0	0	0	0	0	0	0
7–16	12.2	11.7	12.2	13.4	12.4	16.2	19.8	18.3	17.1	17.8	1.51	0	0	0	.20	.49	.34
7–21	16.9	16.9	14.7	13.8	15.6	18.1	21.4	20.0	18.8	19.6	1.66	0	.01	.01	.18	.01	.10
7–28	11.9	14.7	14.2	14.2	13.8	17.3	20.5	18.5	17.2	18.4	0	0	0	0	0	0	0
7–31	9.0	10.2	10.7	11.5	10.4	23.2	17.7	17.9	17.5	19.1	.81	0	.01	.01	.04	.09	.06
8–4	9.8	10.6	12.1	12.7	11.3	16.0	17.3	18.1	16.9	17.1	.05	0	0	0	.01	0	.01
8–21	17.9	10.2	8.3	9.5	11.5	20.7	18.4	19.3	17.1	18.9	2.22	.01	.04	.02	.56	.88	.72
8–25	20.6	19.0	18.4	16.9	18.7	16.6	20.5	18.6	15.9	17.9	2.56	0	.34	.17	1.70	1.74	1.72
9–2	18.9	18.3	17.1	16.6	17.7	14.0	19.2	18.9	16.3	17.1	.74	0	.06	.03	.30	.27	.28
9–15	13.0	13.3	12.7	12.3	12.8	12.7	14.1	14.2	13.8	13.7	.46	0	0	0	.04	.08	.06
10–3	10.1	11.6	11.1	12.3	11.3	10.9	14.9	13.8	13.3	13.2	.88	*0	*.01	.01	0	0	0
10–7	12.4	11.3	10.5	11.0	11.3	12.5	14.4	13.6	12.9	13.4	.60	0	.01	.01	0	.01	.01
10–15	16.2	15.4	14.3	13.8	14.9	19.3	20.6	16.9	15.7	18.1	2.33	0	.03	.02	.14	.11	.12
10–29	15.5	14.5	13.5	14.7	14.6	19.7	20.9	18.1	15.8	18.6	2.74	0	.04	.02	.54	.41	.48

*See descriptive notes.

moisture under the bare surface are connected by dotted lines. These connecting lines have been drawn to aid the reader in studying the soil moisture under a given surface cover, from point to point across the diagrams. No attempt has been made to show the daily fluctuations. The lines have been drawn practically straight from point to point, whereas, in the case of an increase in the amount of moisture, the line, in order to show the conditions accurately, should have been drawn on a slightly downward slope until the day of heavy rainfall and should then have risen more or less abruptly to the higher percentage. Although the diagrams were prepared by platting percentages as ordinates against dates as abscissas, scales showing the actual amounts of water in the soil in inches depth, for the two foot depth of soil involved, have been added at the edges of the sheets.

Notes to Accompany Table 3

On account of the condensed form of table 3 it has not been possible to include descriptive notes. Since such notes are important in any study of the individual records, they are reproduced, herewith, arranged chronologically so that any date can be easily located. Asterisks have been inserted in table 3 after the quantities for which descriptive notes are available.

March 6, 1915.—Average percentage based on two samples taken at this depth.

March 16, 1915.—Average percentage based on three samples taken at this depth. Values given for depths of 18 and 24 inches are questionable and have not been used in computing the average.

April 19 and 28, 1915.—Average percentage based on two samples taken at this depth.

May 3, 5, 22, and 28, 1915.—Average percentage based on two samples taken at this depth.

May 30, 1915.—Runoff was some greater than value given, due to clogging of sewer pipe.

June 4, 1915.—Average percentage based on two samples taken at this depth.

July 29, 1915.—Runoff was some greater than value given, due to clogging of sewer pipe.

Sept. 7, 1915.—Ground within these plats spaded thoroughly to a depth of about six inches.

Nov. 30, 1915.—Light snow on ground. Ground frozen to a depth of about one inch.

Dec. 11, 1915.—Sleeting at time of observation.

Jan. 6, 1916.—Soil under bare surface frozen to a depth of about three inches.

Jan. 14, 1916.—Soil under bare surface frozen to a depth of about five inches.

Jan. 25, 1916.—Runoff due to rain falling on frozen saturated soil surface.

Feb. 2, 1916.—Soil under the bare surface frozen to a depth of about two inches.

Feb. 17, 1916.—Soil under the bare surface frozen to a depth of from one to four inches, but soft on top. Soil under sod not frozen.

Feb. 28, 1916.—Soil under the bare surface frozen to a depth of about five inches. Soil under sod frozen to a depth of about four inches.

Mar. 9, 1916.—Ground thawing out.

Mar. 16, 1916.—Soil under bare surface frozen to a depth of about a half an inch. Soil under the sod frozen to a depth of about an inch. About six inches of snow on the ground.

May 12, 1916.—Ground within these plats spaded thoroughly to a depth of about four inches.

June 3, 1916.—Record probably low due to runoff overtopping side of plat at lower corner.

June 19, 1916.—Surfaces within these plats covered with a dense growth of white clover and bluegrass about twelve inches high.

July 5, 1916.—Grass and weeds removed from these plats, and ground spaded.

Aug. 7, 1916.—Runoff from sloping plat with bare soil surface probably low due to leakage. Grass in sod covered plats about six inches high.

Sept. 6, 1916.—Runoff record for level bare soil plat probably too low due to can overflowing.

Sept. 9, 1916.—Gravel encountered at depth of twenty-four inches under bare surface. Blue grass in sod covered plats three to six inches high.

Sept. 22, 1916.—Ground within bare soil plats spaded to a depth of about three inches. Blue grass in sod covered plats about five inches high.

Nov. 20, 1916.—Grass in sod covered plats about two inches long and dying.

Dec. 4, 1916.—Samples not taken under sod on account of rain.

Dec. 27, 1916.—Runoff due to melting snow, and to rain falling on frozen ground.

Jan. 8, 1917.—Soil not frozen. Dead grass from one to five inches long in sod covered plats.

Jan. 22, 1917.—Soil under bare surface frozen to a depth of about three inches. Bare soil plats about half covered with snow about a half an inch deep. No snow on sod plats.

Jan. 31, 1917.—Soil not frozen.

May 5, 1917.—Data questionable, results not used in computing averages.

May 25, 1917.—Grass two to twelve inches long on sod covered plats. Weeds removed from bare soil plats.

June 30, 1917.—Record may be slightly low due to leakage.

July 14, 1917.—Record uncertain due to clogging of tile entrance.

Dec. 3, 1917.—Owing to the unusually severe winter weather no records were taken during the remainder of this month or during the month of January, 1918. The total precipitation in January, two-thirds of which was snowfall, was 3.46 inches at the Dayton U. S. Weather Bureau Station and 3.87 inches at the Dayton cooperative station.

Feb. 11, 1918.—Snow and ice practically gone, ground frozen to a depth of about eight inches. Records of runoff uncertain due to overtopping of cans and due to water entering plats from outside snow accumulations. Precipitation measurements uncertain; value of 5.26 inches given was observed at the Dayton cooperative station.

Feb. 26, 1918.—Record low due to can overflowing.

May 14, 1918.—Record probably low due to clogging of tile entrance.

June 26, 1918.—Placed wire mesh over entrance to tiles.

July 17, 1918.—Sample disturbed in drying.

July 25, 1918.—Record probably low due to leakage around tile.

Aug. 23 and 28, 1918.—Sample disturbed in drying.

Oct. 3, 1919.—Grass about eight inches long on level sod covered plat, and about two to six inches long on sloping sod covered plat.

It is believed that all records of soil moisture obtained during the summer and fall of 1919 are slightly high compared with the preceding records, due either to taking the samples a little farther away from the plats, where the soil and topography were slightly different, or to getting them more thoroughly dried.

Accuracy of the Data

The data is believed to be sufficiently accurate for the purposes for which it was collected. Although difficulties were encountered, particularly during the first year, they were finally overcome in most instances.

The soil samples were taken for the purpose of learning about how much water was in the ground before and after rains, especially when runoff occurred, rather than for making thorough studies of soil moisture. Consequently the records should not be used indiscriminately in any detailed study of the subject. Any individual value given in table 3 may be considerably in error. Due to the difficulties encountered in taking, drying, and weighing the samples, no single percentage is probably accurate to within less than one per cent; that is, a value given as 5 might actually be 4 or 6, or a value given as 20 might actually be 19 or 21. Possibly a few of the minimum records are low due to not getting the samples entirely dry. It must also be remembered that on account of the slight differences in soil texture and the variations in surface configuration within the limited area in which the samples were taken, samples taken on different dates may not be strictly comparable. Probably this effect is even more important than the errors in observation. These conditions, however, are not so important in considering the average moisture content of the upper two feet of soil, as given in columns 6 and 11 of table 3.

The precipitation records are believed to be accurate in all cases except where the greater part of the precipitation occurred as snow. The two rain gages were well located with respect to obstructions and the readings generally checked to within .05 of an inch.

The runoff records for the level plats and for the sloping sod plat are believed to be as accurate as the precipitation records, except where the runoff was caused by the melting of large quantities of snow. There is no doubt but that all of the runoff from these plats entered the runoff tanks and that the amounts were accurately measured. The depths in the runoff tanks could

easily be measured to eighths of an inch, corresponding approximately to hundredths of an inch on the plats. The records for the sloping bare soil plat are somewhat uncertain in several instances, as indicated in the preceding notes.

SOIL MOISTURE

The records of soil moisture, given in table 3, furnish interesting information regarding the conditions at this particular location and pertaining to this particular soil. From the percentages given in table 3 and the weight per cubic foot of the soil, given in table 2, it is possible to discuss the dryest condition which the soil ever reaches, the maximum amount of water that the soil can contain, the maximum amount that it can hold against the force of gravity, the variations throughout the year, the amount of water absorbed during rains, and the rate at which the ground drys out after the rain ceases.

Minimum Records

A study of the records given in table 3 shows that during the length of time covered by the observations the soil was dryest on August 2, 1916. The determinations made on that date showed an average moisture content of only 4.7 per cent for the soil under the sod covering and only 3.1 per cent for the soil under the bare surface, amounts corresponding to 1.80 and 1.19 inches, respectively, for the depth of two feet in which the samples were taken. Although these values may be slightly low due to not getting the samples thoroughly dried, it is known from other information that the ground at this time was baked hard and was very dry, probably as dry as it ever gets. The water in the soil was probably all hygroscopic water. It is unlikely that any further appreciable evaporation or transpiration could take place. Practically all vegetation, including the larger bushes and trees, had been wilting for several days. The wilting coefficient, calculated from the mechanical analyses given previously, by the methods explained on page 69 of Bulletin 230 of the Bureau of Plant Industry,* would be about 12.3 per cent for the sample taken near the level plats and about 13.7 per cent for the sample taken near the sloping plats. Although values as high as these, and higher, are given for loam and clay loam

*The Wilting Coefficient for Different Plants and its Indirect Determination, by Lyman J. Briggs and W. L. Shantz, Bulletin 230 of the Bureau of Plant Industry, U. S. Department of Agriculture, 1912.

soils, in the above mentioned publication, these values seem slightly high for the Moraine Park soil. Observations showing values smaller than these were made at several times when no evidences of wilting could be detected and when there was no reason to believe that the records might be low. According to Bulletin 230 the values of the hygroscopic coefficient would be 0.68 times the values of the wilting coefficient or about 8.4 and 9.3 per cent respectively for the two samples.

The records at the different depths on August 2, 1916, were as follows:

	Depth in Inches 6	12	18	24	Ave.
Moisture under sod, percent	3.5	4.7	4.5	6.1	4.7
Moisture under bare surface, percent	2.1	2.8	3.5	3.9	3.1

It will be noticed that the amount of moisture in the soil increased as the depth increased, for both types of surface covering; also that the amount under the sod was greater, at each depth, than the amount under the bare surface. The percentages at the different depths were, themselves, minimum values for the entire period of record, in all cases except at the depth of 24 inches under the bare surface where a value of only 3.1 per cent was obtained on July 24, 1916, the preceding date on which samples were taken. It is probable, however, that the soil at this depth was actually drier on August 2 than on July 24, and that the opposite condition shown by the data is due to errors in observation or in securing comparable samples.

The amount of moisture in the soil was also very low in August, 1918, the measurements of August 19 showing the following percentages:

	Depth in Inches 6	12	18	24	Ave.
Moisture under sod, percent	6.1	5.5	5.5	6.1	5.8
Moisture under bare surface, percent	4.5	6.9	6.9	7.9	6.5

It will be noticed that on this date there seemed to be a little more soil moisture under the bare surface than there was under the sod. Under the bare surface the percentage of moisture seemed to increase with the depth, while under the sod it seemed to be about the same at all depths.

It is interesting to note that Widstoe and McLaughlin in their experiments in Utah,* found that in one instance the amount of moisture in the first foot of soil on which crops were

*The Movement of Water in Irrigated Soils, by J. A. Widstoe and W. W. McLaughlin, Bulletin 115 of the Utah Agricultural College Experiment Station, Logan, Utah, May, 1912.

growing was reduced to 5.64 per cent, 40 days after irrigation; and that the amount in the first foot under the bare surface was reduced only to 18.6 per cent, 36 days after irrigation. The value of 5.64 per cent is only about one and a half per cent greater than the minimum Moraine Park record obtained in the first foot of soil under a blue grass sod. However, the value of 18.6 per cent is rather large compared with the value of about 2.5 per cent obtained under the bare surface at Moraine Park. Although there are some differences in soil texture, the real reasons for this wide difference in evaporation are probably the greater percentage of voids in the Utah soil and the differences in the climatic conditions at the two locations. At Moraine Park the percentage of voids in the soil, by volume, is only about 41 while in Utah, where the above experiments were made, it is about 55. In Utah the climate is arid, while in Ohio it is humid. The differences in soil evaporation due to differences in climate were discussed by Buckingham in 1907.* He showed that a moist bare soil in an arid climate dries out rapidly at the surface at first, forming a sort of a dry soil mulch, after which it dries out very slowly; that a moist bare soil in a humid climate dries out less rapidly than in the arid climate at first, so that the dry mulch effect is not produced, and more rapidly later on; the net result being that after several days more water had evaporated from the soil under humid conditions than had evaporated from the soil under arid conditions.

Maximum Records

The maximum percentages of moisture at the different depths, as shown by the data in table 3, occurred on different dates, although some uncertainty exists in this connection due to the difficulties encountered in securing comparable samples. The actual maximum values, not considering a few erratic observations which have been mentioned in the notes as being questionable, are as follows:

	Depth in Inches 6	12	18	24
Moisture under sod, percent	24.8	23.3	23.2	23.6
Moisture under bare surface, percent	23.2	21.8	21.9	21.5

These values seem to indicate that the soil under the sod at a given depth never contains more than about 24 per cent of moisture, and that the soil under the bare surface never contains

*Studies on the Movement of Soil Moisture, by Edgar Buckingham, Bulletin 38 of the Bureau of Soils, U. S. Department of Agriculture, 1907.

more than about 22 per cent. In the preceding discussions it was shown, by calculations based on the specific gravity of the soil particles and the determinations of the unit weight of the soil in place, that the soil would be saturated when it contained an amount of moisture equal to about 25.6 per cent of its dry weight, an amount slightly greater than those given above.

The records seem to indicate that the total amount of moisture in the upper two feet never is more than about 21 per cent of the dry weight of the soil, an amount equivalent to a depth over the surface of 8.06 inches. Samples were taken at several times during the months of January, February, and March, when the soil was probably as nearly saturated as it ever becomes under field conditions. The slight differences in moisture content at the same depth shown by the data at such times are probably due to the difficulties encountered in securing comparable samples or in weighing and drying those taken. The observations which gave the maximum average values for the upper two feet are as follows:

	Depth in Inches 6	12	18	24	Ave.
Moisture under sod, percent	18.2	19.7	22.8	23.4	21.0
Moisture under bare soil, percent	19.7	21.6	21.6	21.5	21.1

The values for the soil under the sod were obtained on March 10, 1919. Those for the soil under the bare surface were obtained on March 24, 1917. On these dates the percentage of moisture seemed to be slightly greater at the greater depths under the sod, but did not differ materially at the different depths under the bare surface.

The average value of 21 per cent shown by the above data probably represents the maximum amount of water that can be held by the Moraine Park soil; that is, the maximum amount of moisture that can be present without any appreciable downward percolation due to gravity taking place,—the quantity frequently referred to as the "moisture-holding capacity." That this is true is indicated, in a way, by the observations of January 24 and February 4 and 11, 1919. The average percentages of moisture found on these dates were as follows:

	Sod	Bare
January 24, 1919	19.8	18.8
February 4, 1919	19.3	17.3
February 11, 1919	19.2	16.7

The total loss in moisture in the 2-foot depth during the 18 days from January 24 to February 11, indicated by these per-

centages, would be equivalent to a depth in inches of 0.23 for the sod and 0.80 for the bare soil. The total precipitation during this period was 0.08 of an inch, thus increasing the amounts of moisture to be accounted for to 0.31 and 0.88 inches, respectively, or to 0.017 and 0.049 inches per day. As the weather during the greater part of this period was clear with temperatures above freezing and some wind blowing, it is quite likely that these amounts represent soil evaporation alone and that consequently no material percolation occurred.

While the amount of moisture that can be held by the soil undoubtedly varies widely with its composition it is interesting to note that Widstoe and McLaughlin, in their investigations in Utah, previously referred to, found that the maximum amount of water that could be held by the Greenville soil under field conditions was a little less than 24 per cent.

Variations in Soil Moisture

The variations in the amount of moisture in the soil at Moraine Park throughout the year are shown graphically by the curves in the lower parts of figures 4 to 8, inclusive. The amount of moisture under the sod is shown by the continuous lines and the amount under the bare surface is shown by the dotted lines.

A study of these diagrams shows that the soil is generally dryest in the late summer or early fall, during the months of July, August, or September; and wettest in the late winter or early spring, during the months of January, February, or March. It has already been pointed out that the minimum val-

Table 4.—Maximum Percentages of Moisture in the Upper Two Feet of Soil at Moraine Park During the Months of June, July, and August

Year	Moisture under Sod, in %			Moisture under Bare Soil, in %		
	June	July	August	June	July	August
1915	13.3	11.9	....	14.4	14.0	....
1916	14.8	8.3	14.9	15.2	9.0	14.2
1917	17.2	17.0	13.1	13.3	13.1	11.4
1918	13.6	16.4	15.0	12.5	13.2	15.8
1919	18 0	15.6	18.7	19.5	19.6	18.9

ues for the entire period of record were obtained in the month of August, and that the maximum values were obtained in the month of March. The curves also show that the amount of

Table 5.—Minimum Percentages of Moisture in the Upper Two Feet of Soil at Moraine Park During the Months of January, February, and March

Year	Moisture under Sod, in %			Moisture under Bare Soil, in %		
	January	February	March	January	February	March
1916	16.4	16.6	17.8	14.4	14.9	15.9
1917	17.0	17.6	18.8	15.1	16.8	17.8
1918	....	18.5	16.6	....	18.9	18.1
1919	18.6	19.2	18.6	18.8	16.7	17.2

moisture gradually increases in the fall, during the months of October, November, and December; that it does not change much during the winter months, even in the absence of rainfall; and that it begins to diminish appreciably in the spring, during the months of April or May, due to the requirements of plants and the higher rates of soil evaporation, both of which are brought about by the higher temperatures.

In the summer months the moisture absorbed during rains is rapidly consumed by transpiration and soil evaporation, as soon as the rain ceases, until the ground becomes so dry that capillary movement of the moisture practically ceases or until the amount of available moisture is replenished by additional rainfall. The rates of soil evaporation and transpiration are so high that the upper two feet of soil at Moraine Park seldom, if ever, becomes filled with capillary water during the months of June, July, and August, even though the rainfall may be considerably greater than normal. The maximum percentages found during these months, shown by the data in table 3, are given in table 4.

It will be noticed that the maximum amount of capillary water that the soil can contain, shown by the preceding discussions to be about 21 per cent, was not reached during any one of the months given in table 4; although the percentages were rather high in the case of the bare soil in the summer of 1919. However, it is believed that the records obtained during the summer and fall of 1919 are slightly high compared with those taken previously. The rainfall was considerably greater than normal during the month of July, 1915, when it amounted to 5.80 inches; during the month of August, 1916, when it amounted to 5.98 inches; and during the month of June, 1917, when it amounted to 6.11 inches, the normal amounts for these months at the Dayton Weather Bureau station being 3.28, 3.01, and 3.96 inches respectively.

During the months of January, February, and March the amount of moisture in the soil, even under the most favorable conditions, seldom gets much below the maximum capillary amount, since plant requirements are nil and soil evaporation is very low. The minimum percentages obtained during these months are given in table 5. Records obtained in March, 1915, are not included since the work had hardly become organized at that time.

It will be noticed that while these values are all somewhat lower than the maximum capillary value of 21 per cent, they are all considerably higher than the minimum values of from 3 to 10 per cent which generally occur during the summer months. No records were obtained during the month of January, 1918, due to the unusually severe winter weather at that time. It is known from other observations, however, that the upper foot of soil became practically saturated during the period from December 21 to 29 due to the melting of about 9 inches of snow; also that the ground froze before this water could percolate to a greater depth, and remained frozen until the thawing period which began February 6.

It will be noticed from the curves in figure 8 that during the months of January and February, 1919, there was little change in the amount of moisture in the soil. Very little drying out seemed to take place between rains although the conditions were probably as favorable for the drying out of the soil as they ever are in the winter. The soil was not frozen; the mean temperatures were comparatively high, being about four degrees above normal; and there was some wind blowing the greater part of the time.

The curves in figures 4 to 8, inclusive, show that the changes in the percentages of moisture in the soil between successive observations were considerably greater during the summer months than they were during the winter months, as, of course, would naturally be expected. An inspection of the data in table 3 shows that while the individual observations vary greatly, partly due to differences in soil texture and to errors of observations, the moisture content of the first 6-inch layer of soil seems to vary more than that of the deeper layers. Interesting data on variations in soil moisture at different depths was obtained near Akron, Colorado, by H. L. Shantz, in the summer of 1909.*

*Natural Vegetation as an Indicator of the Capabilities of Land for Crop Production in the Great Plains Area, by H. L. Shantz, Bulletin 201 of the Bureau of Plant Industry, U. S. Department of Agriculture, 1911, page 31.

It was there found that during the period from June 10 to September 10 the rainfall did not affect the moisture content of the soil below a depth of 18 inches, although on July 7 the rainfall amounted to 2.40 inches. However, a rainy period during the last of May and the first part of June had some effect on the moisture content of the soil down to depths of about 3 feet. At Moraine Park, the moisture content of the soil from 18 to 24 inches below the surface seemed to be affected by the rainfall at times during the summer. This difference in depth of penetration at the two locations is probably due to a difference in soil texture.

Records showing variations in soil moisture have been published by numerous investigators. To mention all such data is beyond the scope of this publication. However, the observations by King, published by the Bureau of Soils,* should be referred to since they gave valuable data on the moisture content, at different depths, of eight different soils, under various conditions of cultivation and fertilization, in four different states.

Evaporation and Transpiration

It is interesting to compute the daily rates of evaporation and transpiration for short periods of time from some of the records given in table 3. This has been done for a few selected periods where the data is most reliable. Periods have been chosen in which the rainfall was not excessive, in which there was no appreciable surface runoff, and in which it is believed that there was no percolation of moisture into the underlying beds of sand and gravel. It has been assumed that the decrease in the amount of moisture in the soil in each case, was caused by evaporation and transpiration, and that no moisture was drawn upward by capillary action from the sand and gravel, assumptions which are probably not greatly in error.

The data computed in this manner is given in table 6. The moisture in the soil, in per cent, at the beginning and ending of each period, the amount of water in inches depth corresponding to the decrease in moisture percentage, the total evaporation, and the evaporation in inches per day, are given for the soil under the sod and for the soil under the bare surface. The term evaporation has been used in the table headings to include transpiration as well as soil evaporation. The total rainfall, the num-

*Investigations in Soil Management, by F. H. King, Bulletin 26 of the Bureau of Soils, U. S. Department of Agriculture, 1905, pages 167-191.

Table 6.—Maximum Rates of Evaporation and Transpiration at Moraine Park

Period	Number of Days	Mean Relative Humidity %	Mean Temperature Degrees F.	Rainfall Inches	Under Sod Cover: Moisture in Soil Begin %	Under Sod Cover: Moisture in Soil End %	Under Sod Cover: Change in Inches	Under Sod Cover: Total Evaporation Inches	Under Sod Cover: Evaporation per Day Inches	Under Bare Soil: Moisture in Soil Begin %	Under Bare Soil: Moisture in Soil End %	Under Bare Soil: Change in Inches	Under Bare Soil: Total Evaporation Inches	Under Bare Soil: Evaporation per Day Inches
May 8–12, 1916	4	53	63	0.10	16.5	15.5	0.38	0.48	0.12	12.3	12.2	0.04	0.14	0.04
May 12–20, 1916	8	65	58	.10	15.5	9.0	2.50	2.60	.32	12.2	10.4	.69	.79	.10
May 20–23, 1916	3	72	63	1.05	9.0	9.7	—.27	.78	.26	10.4	10.6	—.07	.98	.33
June 21–July 5, 1916	14	66	72	.15	14.8	8.3	2.50	2.65	.19	14.5	9.0	2.11	2.26	.16
July 5–24, 1916	19	69	79	.32	8.3	8.1	.07	.39	.02	9.0	4.9	1.57	1.89	.10
July 24–Aug. 2, 1916	9	65	82	.50	8.1	4.7	1.30	1.80	.20	4.9	3.1	.69	1.19	.13
Aug. 8–21, 1916	13	72	77	.12	14.9	10.2	1.80	1.92	.15	14.2	4.7	3.65	3.77	.29
Aug. 21–28, 1916	7	67	72	.80	10.2	9.3	.34	1.14	.16	4.7	3.7	.38	1.18	.17
Sept. 9–22, 1916	13	66	63	.06	16.2	8.7	2.88	2.94	.23	9.9	7.4	.96	1.02	.08
Sept. 29–Oct. 6, 1916	7	70	59	.01	16.4	9.3	2.73	2.74	.39	11.3	7.9	1.30	1.31	.19
May 5–12, 1917	7	85	45	.15	18.5	13.2	2.03	2.18	.31	20.8	13.2	2.92	3.07	.44
May 14–21, 1918	7	72	69	.38	19.2	15.8	1.30	1.68	.24	18.4	12.4	2.30	2.68	.38
May 21–29, 1918	8	72	74	.29	15.8	11.3	1.73	2.02	.25	12.4	11.2	.46	.75	.09
July 1–11, 1918	10	65	69	.00	16.3	10.2	2.34	2.34	.23	10.8	7.7	1.19	1.19	.12
July 25–Aug. 9, 1918	15	79	79	.27	16.1	5.8	3.96	4.23	.28	13.2	6.5	2.57	2.84	.19
Aug. 23–28, 1918	5	72	74	1.54	15.0	10.9	1.57	3.11	.62	15.8	† 6.0	1.88	3.42	* .68
May 21–29, 1919	8	73	62	.80	18.8	16.3	.96	1.76	.22	19.8	17.6	.84	1.64	.20
June 18–July 1, 1919	13	70	74	.38	18.0	13.5	1.73	2.11	.16	19.5	18.3	.46	.84	.06
July 1–July 9, 1919	8	58	78	.00	13.5	10.6	1.11	1.11	.14	18.3	16.2	.80	.80	.10
July 21–28, 1919	7	66	78	.00	15.6	13.8	.69	.69	.10	19.6	18.4	.46	.46	.06
July 28–Aug. 4, 1919	7	67	75	.86	13.8	11.3	.96	1.82	.26	18.4	17.1	.50	1.36	.19
Sept. 2–15, 1919	13	63	71	.46	17.7	12.8	1.88	2.34	.18	17.1	13.7	1.30	1.76	.14
Sept. 15–Oct. 3, 1919	18	67	69	.88	12.8	11.3	.57	1.45	.08	13.7	13.2	.19	1.07	.06

*Probably too low.
†Average for depth of from 12 to 24 inches.

ber of days, the mean relative humidity, and the mean temperature are also included for each period. The maximum rates of evaporation in inches per day have been set in bold face type. The minimum values have no significance.

It will be noticed that the rates of evaporation vary from 0.02 to 0.62 inches per day for the soil under the sod and from 0.04 to 0.68 inches per day for the soil under the bare surface. The maximum values of 0.62 and 0.68 inches occurred during the 5-day period from August 23 to 28, 1918. The value of 0.68 inches for the soil under the bare surface is probably too low, as indicated in the table. The samples taken in the upper foot of soil under the bare surface on August 28 were disturbed in drying so that the value of 6.0 per cent given for that date is the average for the second foot of depth only. In calculating the evaporation it was assumed that the percentage of moisture in the upper foot of soil on August 28 was the same as on August 23, whereas it probably was a little less.

These average values of 0.62 and 0.68 inches per day for five days are rather unusual. However, a study of the weather records shows that the conditions at that time were favorable for high rates of evaporation. The greater part of the total rainfall of 1.54 inches fell in three separate showers on three different days, August 26, 27, and 28. Considerable sunshine and some wind occurred between showers on these dates, as well as on August 23, 24, and 25.

In this connection it may be noted that Briggs and Shantz, in their experiments at Akron, Colorado, obtained values for plant transpiration, alone, which were somewhat higher than the above values.* Although, there is, of course, a great difference in climate between Dayton and Akron, it may be interesting to give some of their results. During the 10-day period from July 7 to 16, 1914, they obtained the following average daily transpiration rates in inches:

Kubanka wheat	1.21
Galgalos wheat	1.42
Swedish oats	1.31
Burt oats	1.23
Barley	0.67
Rye	0.92

*Daily Transpiration During the Normal Growth Period and Its Correlation with the Weather, by Lyman J. Briggs and H. L. Shantz, Journal of Agricultural Research, U. S. Department of Agriculture, October 23, 1916.

Cowpea	0.96
Siberian Millet	0.78
Northwestern Dent Corn	0.83
Minnesota Amber Sorghum	0.81
Sudan grass	0.66

The daily rate of evaporation from water in a shallow tank during this period was 0.48 inches. The quantities of water used by the plants were determined by weighing. Plants were grown in cans, fitted with covers to prevent soil evaporation, small holes being cut in the covers for the stems. The above transpiration rates were calculated, taking the area of the can as the area occupied by the plant. Probably a somewhat larger area should have been used, since the foliage, in some instances, undoubtedly spread out toward the light beyond the edges of the can. However, if an area twice as great as that of the can had been used, the results would still be comparatively large.

The values of evaporation given for the soil under the sod at Moraine Park, include the water intercepted by the grass and evaporated directly into the air without reaching the soil, the water taken up from the soil by the grass roots and transpired into the atmosphere, and the water evaporated directly from the surface of the soil itself. The values for the soil under the bare surface represent soil evaporation alone. While the accuracy of the data is not such as to warrant definite comparisons, it may be stated that the evaporation rate seems to be a little greater from the bare soil than from the sod for those periods in which there was considerable rainfall, and a little greater from the sod than from the bare soil for those periods in which there was no rainfall or only an insignificant amount.

The rates of soil evaporation and transpiration during the winter months were probably much lower than those given in table 6. There were probably days in the winter, during the months of January and February, when the rates were less than a hundredth of an inch per day. The observations recorded in table 3 are hardly sufficient for a discussion of minimum values. However, they do give some indication of the maximum rates which may occur during the winter months. The comparatively low rates of 0.017 for the soil under the sod and 0.049 for the soil under the bare surface, during the period from January 24 to February 11, 1919, when there was only 0.08 inches of rainfall, have already been noted. These values are probably fairly indicative of the maximum rates at which moisture can be eva-

porated from the soil at Moraine Park, during the months of January and February, when there is no appreciable precipitation. These rates would, of course, have been higher if several light rains had occurred, separated by periods of clear and windy weather. As before mentioned, the conditions at that time were about as favorable for the drying out of the soil as they ever are in the winter. These values would indicate that in the winter the evaporation from bare soil surfaces is greater than from sod surfaces, which seems reasonable.

The records taken during the winter of 1917 and 1918 offer an opportunity for estimating the rate of evaporation from snow surfaces. The greater part of the precipitation between December 3, 1917, and February 11, 1918, occurred as snow, the temperatures being below freezing the greater part of the time. The ground froze to a depth of a few inches during the cold period of December 6 to 18 when the temperature was frequently from 3 to 8 degrees below zero. It then thawed out partly and the upper foot became saturated during the period of December 21 to 29, due to the melting of about 9 inches of snow; after which it froze again and remained frozen until after the observations of February 11. It is doubtful if any appreciable amount of water percolated through the surface soil during the thawing period of December. Deducting the average runoff of 2.66 inches, from the four plats, from the rainfall of 5.26 inches leaves 2.60 inches to be accounted for by soil absorption or evaporation. The former was probably about an inch. The soil samples would indicate an average absorption of 1.65 inches, but a part of this was probably runoff from the hillside above. This leaves 1.60 inches for the total evaporation during the period of 70 days, or about 0.023 inches per day, nearly all of which must have occurred from snow surfaces. The actual daily rates undoubtedly varied a great deal from this average since there were wide variations in temperature and other meteorological conditions. The minimum, mean, and maximum values of relative humidity, temperature, and wind velocity during the 70 days were as follows:

	Minimum	Mean	Maximum
Relative humidity in per cent	51	83	100
Temperature in degrees F.	-16	19	62
Wind velocity in miles per hour	0	11.5	45

There were 18 cloudy days, 22 partly cloudy days, 30 clear days and 31 days on which the precipitation amounted to or exceeded 0.01 of an inch.

It is interesting to note that R. E. Horton* obtained an average rate of 0.028 inches per day for the period of 9 days from December 26, 1913, to January 4, 1914, at Albany, New York, when the mean maximum temperature was 26.6 degrees.

Measurements of evaporation from snow surfaces were also made in the Little Bear Valley of the San Bernardino Mountains, California, where the meterological conditions are considerably different from those at Dayton. The results, given in water supply paper 294,† were as follows:

Month and year	Average Rate in Inches per day
March, 1895	0.08
March, 1896	0.12
January, 1897	0.05
February, 1897	0.10
March, 1897	0.10

Some data on evaporation from ice surfaces in Maine is given in water supply paper 279.**

An evaporation of 0.51 inches in 6 days, with a maximum rate for one day of 0.15 inches and a minimum rate for one day of 0.03 inches, was measured at Lewiston during the period from November 19 to 24, 1905, when the average air temperature was 34.8 degrees and the average relative humidity was 39.3 per cent.

Absorption in Surface Soil

The records given in table 3 and discussed in the preceding pages enable us to study the absorption of the upper two feet of soil, or surface soil, as it may be termed. The term absorption will here be used to mean the water taken up by the soil and held to supply soil evaporation and transpiration after the rain ceases. It will not include the water that percolates through the surface soil into the underlying gravel to maintain ground water flow.

*Evaporation from Snow and Errors of Rain Gage when used to catch Snowfall, by R. E. Horton, Monthly Weather Review, February, 1914, page 99.

†An Intensive Study of the Water Resources of a Part of Owens Valley, California, by Charles H. Lee, U. S. Geological Survey Water Supply Paper 294, 1912, pages 49 and 118.

**Water Resources of the Penobscot River Basin, Maine, by H. K. Barrows and C. C. Babb, U S. Geological Survey Water Supply Paper 279, 1912, page 120.

Table 7.—Soil Absorption at Moraine Park During Summer Storms

Storm Period	Rainfall	Under Sod			Under Bare Soil		
		Moisture in Soil		Absorption*	Moisture in Soil		Absorption*
	Inches	Before Rain %	After Rain %	Inches	Before Rain %	After Rain %	Inches
Aug. 4– 8, 1916....	4.56	4.7	14.9	3.92	3.1	14.2	4.26
Sept. 5– 6, 1916....	4.12	9.3	15.4	2.34	3.7	9.0	2.03
Sept. 27–29, 1916....	1.68	8.7	16.4	2.96	7.4	11.3	1.50
Nov. 23–24, 1916....	0.84	11.3	16.9	2.15	11.7	15.1	1.30
June 26–30, 1917....	2.90	9.9	17.2	2.80	10.4	13.3	1.11
Oct. 11–19, 1917....	2.02	9.2	16.2	2.69	11.1	16.0	1.88
July 22–23, 1918....	3.11	10.3	16.4	2.34	5.8	9.0	1.23
Aug. 12–23, 1918....	2.30	5.8	15.0	3.53	6.5	15.8	3.57
Aug. 28–Sept. 2, 1918....	1.39	10.9	18.0	2.73	6.0	12.7	2.57

*In upper two feet of soil.

The preceding discussion has shown that throughout the period of about four and a half years covered by the observations the amount of moisture in the upper two feet of soil at Moraine Park varied from a minimum of 4.7 per cent, or 1.80 inches, to a maximum of 21.0 per cent, or 8.06 inches, in the case of the sod covering; and from a minimum of 3.1 per cent, or 1.19 inches, to a maximum of 21.1 per cent, or 8.10 inches, in the case of the bare soil covering; the difference in the actual amounts of water in the 2-foot layer in the two cases corresponding to 6.26 and 6.91 inches, respectively, averaging 6.58 inches. This average value would be the maximum possible absorption at Moraine Park as shown by the records. While the maximum percentages used above were practically reached each winter, the minimum values were reached only once. Consequently this average value of 6.58 inches is one which would very seldom, if ever, be attained during a single storm. For the amount of soil moisture to be increased from the minimum value to the maximum during a single storm would require an exceptional combination of conditions such as the occurrence of a very heavy prolonged rainfall at a time when the ground was dryest. Taking a value of 8 per cent for the minimum amount of soil moisture, a value which is reached practically every summer, the difference between the amount of water in the upper 2 feet during the ordinary dry periods of the summer and the amount present during the winter, would be 5.00 inches. Probably this value is also greater than the maximum amount of water ever absorbed during a single storm.

If the ground is not frozen the proportion of the maximum possible absorption that can be absorbed during a single storm varies with the amount of moisture present when the rain begins. The dryer the soil the greater is the space in which the water can be absorbed. If the rain continues long enough the moisture holding capacity of the upper two feet at Moraine Park will become filled, after which the water will percolate through the underlying sand and gravel as fast as it can move through the surface soil. If the ground is frozen very little moisture will be absorbed unless the duration of the rainfall and the temperatures are great enough to thaw out the ground. The actual amount of water that is absorbed during a given storm, of course, varies also with the nature of the rainfall. If the rainfall intensity is greater than the rate at which the water can soak into the ground, and the surface storage has been filled, the excess water will run off; whereas, if the same total precipitation is distributed through a greater time, it may all be absorbed.

Table 7 gives the larger records of absorption during individual storms, selected from the data in table 3. All records corresponding to depths of two inches or more in the upper two feet are included except in one or two instances where the data seemed questionable. In addition, records corresponding to depths of less than two inches are included for one type of surface covering where the absorption under the other type amounted to or exceeded two inches. The percentages of moisture present before the rain began and after the rain ceased, as well as the total precipitation during each storm period, are also included. The distribution of the rainfall can be seen by referring to figures 4 to 8, inclusive. The maximum values of absorption given in the table are set in bold face type. The minimum values have no special significance.

It will be noticed that in several instances the absorption was greater than the rainfall. The reason for this is that the place where the samples were taken is located near the foot of a steep hill in the direct path of the surface runoff from the hillside. As some runoff occurred during each of the storms recorded in table 7, except the one of September 27 to 29, 1916, the amount of water available to replenish the soil moisture was actually greater than the rainfall. The discrepancy in case of the storm noted is probably due to the difficulties encountered in securing samples representative of average conditions.

It is interesting to note that while runoff occurred on the

plats having the bare surface in all but one of the storms listed in table 7, and on the plats having the sod covering in the greater number of the storms, in no case did the ground become saturated. The greatest amount of moisture found in the soil after the rain ceased was only 18 per cent in the case of the sod covering, measured after the storm of August 28 to September 2, 1918; and only 16.0 per cent in the case of the bare soil, measured after the storm of October 11 to 19, 1917.

Inspection of table 7 shows that the moisture absorbed by the sod is generally greater than that absorbed by the bare soil, as would be expected. There are only two exceptions to this, and in these instances the differences are so small as to come within the limits of possible errors. In one case, that of August 4 to 8, 1916, the values constitute the maxima of the entire record, amounting to 3.92 inches for the sod and to 4.26 inches for the bare soil. This storm, with a total rainfall of 4.56 inches spread rather uniformly over five days, began when the soil was dryer than at any other time during the period covered by the data. In the other case, that of August 12 to 23, 1918, the values are the next largest, amounting to 3.53 inches for the soil under the sod and to 3.57 inches for the soil under the bare surface. The greater part of the total precipitation of 2.30 inches which fell during this period, occurred in three separate showers on three different days, August 12, 14, and 17. These are the only two instances where the absorption exceeded three inches; and it is interesting to note that both of them occurred during the month of August. All of the storm periods given in table 7 occurred in the summer or fall, during the months of June to November, inclusive. As shown in the preceding discussions, it is only during the summer months that the soil becomes dry enough to absorb such large amounts.

The values of 2.34 inches for the soil under the sod and 2.03 inches for the soil under the bare surface, obtained during the period from September 5 to 6, 1916, were caused by a total rainfall of 4.12 inches which fell in the afternoon and evening of the 5th and in the morning of the 6th. The total period of time in which the rain fell was less than 18 hours. Probably 90 per cent of the total precipitation occurred during the 6 hours from 3 to 9 p. m., on the 5th. At the Dayton Weather Bureau station the maximum intensities were 0.43 inches in 5 minutes, 0.79 inches in 10 minutes, and 1.75 inches in 30 minutes.

The values of absorption given in table 7 are believed to

be less than the amounts that actually occurred during the given storms, the reason being that while samples were always taken within a few hours or a day after the rain ceased quite frequently samples had not been taken for several days before the rain began. In calculating the values given in the table no allowances were made for the evaporation which must have occurred between the time the samples were taken and the time the rain began.

Table 8.—Soil Absorption at Moraine Park During Winter Storms

Storm Period	Rainfall	Under Sod			Under Bare Soil		
		Moisture in Soil		Absorption*	Moisture in Soil		Absorption*
	Inches	Before Rain %	After Rain %	Inches	Before Rain %	After Rain %	Inches
Dec. 12–17, 1915	1.75	15.6	17.3	0.65	16.7	16.3	-0.15
Apr. 20–22, 1916	1.08	17.7	19.8	0.80	13.7	15.3	0.61
Mar. 13–14, 1917	1.44	19.8	19.0	-0.30	17.8	20.3	**0.96**
Dec. 9–13, 1918	1.59	17.4	20.0	**1.00**	16.9	19.3	0.92
Mar. 5–10, 1919	1.09	19.9	21.0	0.42	18.0	19.6	0.61
Mar. 15–18, 1919	2.97	20.4	20.6	0.07	17.2	18.4	0.46
Mar. 26–27, 1919	0.85	18.6	20.6	0.77	17.7	19.2	0.57
Apr. 9–11, 1919	1.53	18.6	19.4	0.30	18.0	18.3	0.11

*In upper two feet of soil.

In order to show how much moisture is absorbed by the soil during winter rains a few of the larger records of absorption during individual winter storms, selected from the data in table 3, are assembled in table 8. The percentages of moisture present before the rain began and after the rain ceased and the total precipitation during each storm period are included, as in table 7. Only storms occurring during the months of December to April, inclusive, at times when the ground was not frozen, are considered. Maximum values are indicated as before.

The negative values appearing in table 8 are probably due to errors in observation as it is hardly likely that the soil was drier after the rain than it was before. It will be noticed that in only one case, that of the soil under the sod in December, 1918, was the absorption as much as an inch. There does not seem to be much difference in the winter between the absorption under the sod and under the bare soil surface. The ground was frozen during the greater number of storms which occurred in the months of January and February, and consequently such records were not included in table 8.

It will be observed that in the greater number of storms listed in table 8 the soil was nearly saturated when the rain began and was practically saturated when the rain ceased. It is interesting to point out that although the ground was saturated by the storms of March 5 to 10 and 26 to 27, 1919, no trace of runoff could be observed on any of the plats. In these instances the rates of precipitation must have been less than the rate at which the water could percolate through the two-foot layer of surface soil.

SURFACE RUNOFF

While the records in table 3 cannot be used to solve all problems connected with surface runoff, they do furnish some interesting information. They enable us to study the conditions under which surface runoff begins, the rates at which moisture can be absorbed by the soil, the relation of the total surface runoff to the total rainfall, during storm periods as well as during the year, and the amount of water that percolates through the surface soil to maintain the ground water flow of the streams. They also enable us to study the effect of variations in the slope of the ground, in the nature of the surface covering, in the amount of moisture in the soil when the rain begins, and in the character, intensity, and duration of the precipitation.

Surface Slope and Surface Covering

In order to study the variations in surface runoff caused by variations in surface slope and in surface covering, the larger runoff records of table 3 are assembled in table 9. Runoff measurements for all plats are included for all dates on which the observations show a total runoff of an inch or more on at least one of the plats. The differences in runoff due to variations in surface slope and to variations in surface covering have been calculated and are given in the last four columns of the table. The observed total rainfall is also included. Maximum values of the various quantities are set in bold face type as in preceding tables. It should be pointed out that the amounts of rainfall and runoff, here given, did not occur on the date of observation noted in the first column but occurred during the time between the date noted and the preceding date on which observations were made. An idea of the probable distribution of the runoff

Table 9.—Effect of Slope and Surface Cover on Runoff at Moraine Park

Date of Observation	Rainfall in Inches	Runoff, in Inches				Differences in Runoff, in Inches, due to			
		Sod Cover		Bare Soil		Variations in Slope		Variations in Surface Cover	
		Level	Sloping	Level	Sloping	Sod	Bare	Level	Sloping
Aug. 18, 1915....	4.22	0.61	1.33	1.61	1.73	0.72	0.12	1.00	0.40
June 3, 1916....	1.99	0	0.04	1.19	*1.11	0.04	—0.08	1.19	1.07
Aug. 7, 1916....	3.63	0	0.24	1.55	*0.97	0.24	—0.58	1.55	0.73
Sept. 6, 1916....	4.32	0	0.05	*1.90	1.66	0.05	—0.24	1.90	1.61
Jan. 8, 1917....	2.04	0	0	1.04	0.41	0	—0.63	1.04	0.41
June 11, 1917....	2.77	0.01	0	1.08	0.73	—0.01	—0.35	1.07	0.73
June 30, 1917....	2.90	0.02	0.03	*1.73	1.66	0.01	—0.07	1.71	1.63
Aug. 25, 1917....	3.04	0.03	0.01	1.35	1.52	—0.02	0.17	1.32	1.51
Feb. 11, 1918....	5.26	†2.29	†2.74	†3.05	†2.56	0.45	—0.49	0.76	—0.18
Feb. 26, 1918....	2.54	0	0.16	1.47	*0.37	0.16	—1.10	1.47	0.21
July 23, 1918....	3.11	0.03	0.11	2.23	2.20	0.08	—0.03	2.20	2.09
Sept. 26, 1918....	3.54	0	0.01	1.17	1.24	0.01	0.07	1.17	1.23
Aug. 25, 1919....	2.56	0	0.34	1.70	1.74	0.34	0.04	1.70	1.40

*Record believed to be low.
†Record uncertain due to snow accumulations.

can be obtained by referring to the rainfall distribution shown in figures 4 to 8, inclusive.

Some of the runoff measurements given in table 9 are believed to be too low or are questionable as indicated. More detailed notes on these are given at the end of table 3. Such notes are given only in cases where there was some definite reason to question the measurement. Probably several additional records for the sloping plat with the bare soil surface are too low since in several instances the runoff measured was appreciably less than that from the level plat with the same surface covering, as indicated by the minus signs in the difference column. This condition appears to have existed more often during the larger storms, such as those listed in table 9, than during the smaller ones.

In spite of these uncertainties, however, the data in table 9 offers some interesting information. It will be noticed that the differences between the runoff from the level ground and from the hillside, either on the sod or on the bare soil, are considerably less than the differences between the runoff from the sod and from the bare soil, either on the level ground or on the hillside. The maximum values of the former amount to 0.72 and 0.17 inches, respectively, for the sod and bare soil surfaces; while the maximum values of the latter amount to 2.20 and 2.09 inches, respectively, for the level and sloping locations. This would indicate that in small areas variations in surface covering have a relatively greater effect on runoff than do variations in surface slope.

The differences between the runoff from the level ground and from the hillside, in the case of the sod covering, where there is no reason to doubt the accuracy of the results, are seen to be small in all cases, especially in comparison with the total amount of the precipitation. The maximum difference of 0.72 of an inch, found in the measurements of August 18, 1915, was only about 17.1 per cent of the rainfall. It might be mentioned that this record covered two separate showers, each of which probably caused some runoff; so that the absolute value of 0.72 of an inch would be larger than that caused by either of the showers. The next largest difference was found in the measurements of February 11, 1918, amounting to 0.45 of an inch, or to about 8.6 per cent of the precipitation. In this case the runoff was caused almost entirely by melting snows at a time when the ground was saturated and was frozen to a depth of

about eight inches. For such conditions the effects of variations in surface covering, as well as in surface slope, are probably much less important than in cases where the soil can absorb a large part of the precipitation. During the storm of July 7, 1915, not included in table 9 because the runoff did not amount to an inch on any of the plats, the difference was 0.35 of an inch, or about 16.6 per cent of the total rainfall. During this storm the greater part of the rain fell in about an hour. An examination of the data in table 3 shows that out of the 95 observations in which some runoff occurred from the sod plats, in only 5 cases did the amount from the sloping plat exceed that from the level plat by as much as 0.25 of an inch, the difference generally being much less than this.

In the case of the sod covering the maximum quantity of runoff obtained from the sloping plat when there was no runoff from the level plat was 0.34 of an inch. This value was found in the observations of August 25, 1919, when the total rainfall amounted to 2.56 inches. In the case of the bare soil surface the corresponding value, which does not appear in the table, was 0.13 of an inch, this amount being measured on November 30, 1918, when the total precipitation was only 0.73 of an inch.

On the other hand the differences between the runoff from the sod and from the bare soil are seen to be comparatively large. This is true for the sloping plats as well as for the level plats, in spite of the rather low values of the runoff from the bare soil plat on the hillside. Leaving out of consideration the data for February, 1918, when the conditions were abnormal as explained above, the differences for the level ground are seen to vary from 1.00 inch, or about 24 per cent of the rainfall, on August 18, 1915, to 2.20 inches, or about 71 per cent of the rainfall, on July 23, 1918; and those for the sloping ground are seen to vary from 0.40 of an inch, or about 9 per cent of the rainfall, on August 18, 1915, to 2.09 inches, or about 70 per cent of the rainfall, on July 23, 1918, the extreme values for the two locations occurring on the same date in each case.

The fact that variations in surface runoff due to variations in surface cover are much greater than those due to variations in surface slope is also seen by referring to the runoff records platted in figures 4 to 8, inclusive. A study of these diagrams shows that while the occurrence of appreciable runoff was comparatively frequent in the case of the bare soil, it was very infrequent in the case of the sod. In fact, runoff amounting to,

or exceeding, 0.10 of an inch was observed on only 4 dates on the level sod plat as against 60 dates on the level bare soil plat; and on only 12 dates on the sloping sod plat as against 77 dates on the sloping bare soil plat. Melting snow or rain occurring at times when the ground was frozen caused the runoff on the level sod plat in 3 of the 4 cases and on the sloping sod plat in 5 of the 12 cases.

The reason that runoff seldom occurs on the sod plats, even in unusually heavy rainstorms, is that the soil is filled with roots down to the depth where the percentage of sand and gravel present is large. Consequently the soil is unusually pervious, and the water is able to percolate downward practically as fast as the rain falls, even during unusually intense downpours.

It thus appears that on the Moraine Park plats the nature of the surface covering has an important effect on the runoff conditions while the slope of the ground is relatively unimportant.

Table 10.—Surface Runoff and Soil Moisture at Moraine Park During Summer Storms

Storm Period	Rainfall in Inches	Runoff in Inches		Moisture in upper 6 inches of Soil, in %*		Ratio of Runoff from Bare Soil to Rainfall, in %
		Sod	Bare Soil	Sod	Bare Soil	
June 1– 2, 1915..	2.01	0.02	0.35	12.5	11.9	17
July 7, 1915..	2.11	0.24	0.70	11.2	14.1	33
Sept. 5, 1915..	2.15	0	0.32	14.4	13.9	15
May 3– 7, 1916..	1.81	0	0.59	15.4	13.0	33
Aug. 4– 7, 1916..	3.63	0.12	1.26	14.9	11.9	35
Sept. 5– 6, 1916..	4.12	0.02	1.78	13.9	15.1	43
May 26–28, 1917..	2.28	0.01	0.90	15.3	17.0	39
June 2– 9, 1917..	2.77	0.01	0.90	13.9	11.4	32
June 26–28, 1917..	2.86	0.02	1.70	16.4	13.5	59
July 7, 1917..	1.25	0.01	0.30	11.9	11.9	24
July 16–17, 1917..	1.43	0.01	0.40	14.8	13.4	28
July 23–26, 1917..	0.96	0.01	0.42	16.3	12.2	44
Aug. 21–22, 1917..	3.02	0.02	1.44	15.3	10.0	48
May 11–12, 1918..	2.75	0.02	0.85	19.3	19.5	31
June 6, 1918..	1.43	0	0.28	15.0	15.4	20
Aug. 12, 1918..	1.21	0.02	0.66	12.2	7.9	54
Aug. 24, 1919 .	2.56	0.17	1.72	20.6	16.6	67

*After rain ceased.

It was in view of this condition that the average values of the runoff for the two types of surface covering were calculated and recorded in columns 15 and 18 of table 3. The following studies will generally be confined to these average values.

The effect of surface slope on the total amount of runoff undoubtedly becomes more important as the size of the area in-

creases, due to the longer time required for the runoff to reach the drains. A part of the water which ran off at Moraine Park probably would have been absorbed if it had been required to flow several hundred feet to the drains instead of less than seven, since total absorption varies with the length of time the surface is covered with water. This additional absorption would undoubtedly have been larger in the case of the level plats than in the case of the sloping plats, due to the effect of slope on velocity.

Surface Runoff and Soil Moisture

It was pointed out in the discussion of the amount of water absorbed by the soil during storms that surface runoff occurred at Moraine Park at times during the summer when the upper two feet of soil was not saturated. In order to study in more detail the effect of soil moisture on the surface runoff during the summer, the records of table 3 which are best suited for such a study are arranged in table 10. The records of rainfall, runoff, and amount of moisture in the upper 6 inches of soil after the rain ceased have been included for storms occurring during the months of May to September, inclusive, where the average runoff from either the sod or the bare soil amounted to or exceeded a quarter of an inch. Storms have not been included where there was any opportunity for the ground to dry out appreciably between the time the rain ceased and the time the samples were taken. The ratio of the runoff from the bare soil to the total rainfall is given in the last column. In a few cases, where observations had not been made just before and just after the given periods, the total precipitation was calculated from the Dayton records, assuming that the ratio of the total rainfall during the storm to the total observed was the same at both locations. In such cases it was also assumed that all of the runoff occurred during the storm period.

The data in table 10 shows that while a considerable proportion of the rainfall ran off of the bare soil during each of the storms included, in only one case, that of May 11 to 12, 1918, was the upper 6 inches of soil found to be nearly saturated after the rain had ceased. The samples taken after this storm showed a moisture content of 19.5 per cent for the upper 6 inches under the bare surface. The corresponding observations for the other storms included in the table are seen to vary from 7.9 per cent to 17.0 per cent, averaging about 13.0 per cent. The preceding discussion of soil moisture showed that the soil under the bare

surface can contain a quantity of water equivalent to 25.6 per cent of its dry weight, that single observations showed as much as 23 per cent for a depth of 6 inches, and that average amounts for the upper 2 feet of as much as 21 per cent were measured. It thus appears that the runoff during these storms was caused by the rain falling faster than it could soak into the ground, rather than to rain falling on a saturated soil.

The storms of August 4 to 7, 1916, September 5 to 6, 1916, June 26 to 28, 1917, August 21 to 22, 1917, and August 12, 1918, occurred at times when the ground was unusually dry and was baked hard. The other storms occurred at times when the ground was neither unusually dry nor unusually wet. It may be interesting to note that considerable flood runoff occurred throughout the Miami Valley during the storms of July 7, 1915, May 3 to 7, 1916, June 26 to 28, 1917, July 16 to 17, 1917, and May 11 to 12, 1918; also that some flood runoff was observed at a few of the gaging stations on the smaller streams of the valley during each of the other storms included in table 10.

Some interesting observations on surface runoff during intense rates of precipitation when the soil was unusually dry were made at Carrmonte, about two miles north of Moraine Park, on August 5 and 6, 1916. Rain began falling at an intense rate at 2:40 p. m. August 5. At 2:50 p. m. the precipitation, which had been fairly steady, amounted to 0.56 of an inch, corresponding to an average rate of 3.36 inches per hour for the ten minutes. At this time water was running off wherever there was enough slope in the ground surface to allow it to do so. It was running down a gravel alley which had a comparatively flat slope, and was standing all over a level lawn, running off wherever it could. Before the rain began the ground was unusually dry and was baked hard. In fact it was drier than at any other time during the period covered by the Moraine Park experiments. At 3:20 p. m., when the rain ended, the total precipitation amounted to 1.10 inches. Probably not more than half of this quantity was absorbed by the soil.

At 4:35 p. m. on August 6, rain began falling again at a fairly intense rate. At 4:50 p. m. the precipitation, which had been steady, amounted to 0.37 of an inch, corresponding to an average rate of 1.48 inches per hour for the fifteen minutes. At this time the water was running off the same areas under practically the same conditions as on the preceding day.

Interesting information regarding runoff from a small area

in Arkansas, caused by an intense shower occurring when the ground was dry and baked hard, was given by James H. Fuertes in the Journal of the Western Society of Engineers, April, 1899, page 170. An abstract of his article is given on pages 265 and 266 of Metcalf and Eddy's American Sewerage Practice, Volume I. A total runoff of 0.38 of an inch occurred from an area of about 2400 square feet, the surface of which sloped uniformly at a rate of about 5 feet in 100 feet, due to a total precipitation of 1.3 inches in 37 minutes, 0.71 of which fell in 8 minutes. The maximum rate for 5 minutes was 6 inches per hour, or a total of 0.50 inches in the 5 minutes.

It was also pointed out in the discussion of the amount of water absorbed by the soil during storms, that surface runoff

Table 11.—Winter Storms at Moraine Park Which Did Not Cause Appreciable Runoff

Sorm Period	Rainfall in Inches	Runoff in Inches		Moisture in upper 6" of Soil, in %			
				Sod		Bare Soil	
		Sod	Bare Soil	Before	After	Before	After
Dec. 16–17, 1915	1.50	0.02	0.03	15.6	17.1	15.5	15.6
Jan. 27–31, 1916	2.39	0.01	0.05	16.0	16.4	18.0	16.5
Apr. 1– 2, 1917	0.78	0	0	16.7	19.4	19.7	18.2
Jan. 1, 1919	0.75	0	0	19.4	20.0	19.9	21.1
Mar. 5– 8, 1919	1.09	0	0	16.8	18.2	18.0	19.0
Mar. 15–18, 1919	2.97	0.02	0.06	18.4	19.6	17.6	18.8
Mar. 27, 1919	0.85	0	0	17.1	18.1	16.1	19.2

did not occur on the plats at Moraine Park at times in the winter when the ground was apparently about as wet as it ever is. In order to show this condition more fully the more pertinent records of table 3 are brought together in table 11. Records of rainfall, runoff, and moisture in the upper 6 inches of soil before the rain began and after the rain ceased, are included for storms occurring during the months of December to April, inclusive, where the total precipitation amounted to or exceeded 0.75 of an inch, where the average runoff did not amount to as much as 0.10 of an inch from either the bare soil or the sod, and where there were no complicating conditions which would affect the results. Storms in which the precipitation occurred as snow are not included. In a few cases the Dayton daily records have been utilized in determining the total rainfall during the storm periods, as explained in the discussion of table 10.

A study of the data in table 11 shows that while in two cases the upper 6 inches of soil was not saturated when the rain ceased,

in the remaining instances the ground contained about as much moisture as it can hold under field conditions. Moreover, in the cases where the soil was not saturated, the storms of December 16 and 17, 1915, and January 27 to 31, 1916, the amount of moisture present was as great or greater than in the cases included in table 10. No appreciable runoff occurred from either the bare soil or the sod during any of the storms included in table 11 while considerable runoff occurred from the bare soil during all of the storms included in table 10. The fact that runoff did not occur from the bare soil, where there was no appreciable surface storage, during the storms included in table 11, although the ground was practically saturated in most cases, indicates that in these instances the rates of precipitation were less than the rates at which water could be absorbed or could percolate through the two-foot layer of surface soil into the underlying porous sand and gravel. Although parts of the precipitation on the sod plats, where there was some surface storage, may be accounted for by evaporation, it does not seem probable that any perceptible amount of the precipitation on the bare soil plats could be accounted for in this way. On these plats practically all of the water must have been absorbed by the soil or have percolated into the underlying materials. During the larger storms such as those of January 27 to 31, 1916, and March 15 to 18, 1919, considerable quantities of water must have percolated.

It thus appears that for bare soil, where there is practically no surface storage, intensity of precipitation has an important effect on runoff. If the intensity is greater than the rate at which water can be absorbed by the surface soil, or greater than the rate at which it can percolate through the soil when the ground is already saturated, the excess water must run off. In such cases the amount of runoff must increase as the intensity of rainfall increases. Where the soil is covered with sod or with agricultural crops the surface storage acts as a regulating reservoir, holding the water which falls during the periods when the intensity is greater than the rates at which the water can enter the ground, and allowing it to soak into the soil later, when the precipitation is less intense. Consequently in such cases, variations in the intensity of the precipitation are relatively less important as regards runoff.

Rates of Absorption and Percolation

In the case of the bare soil plats at Moraine Park a study of the intensities of precipitation during some of the storms may

furnish approximate information regarding the rates at which water can be absorbed by, or can percolate through, the two-foot layer of surface soil. The only data on intensities available for such a study are the graphical rainfall records maintained by the U. S. Weather Bureau at Dayton, about five miles north of Moraine Park. During some of the storms for which data is available, such as the local thunderstorm of August 24, 1919, where the total precipitation at the experimental plats was about four times as great as at Dayton, the intensities at the latter location were, of course, quite different from those at Moraine

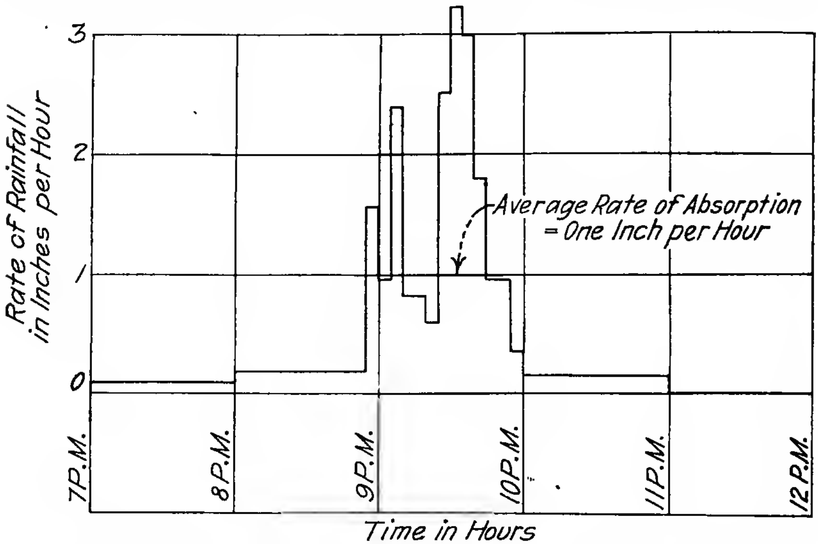

FIG. 9.—RATE OF RAINFALL AT MORAINE PARK DURING THE STORM OF JULY 7, 1915.

The average rate of absorption indicated by the horizontal line cutting through the periods of most intense precipitation, applies only to the bare soil plats.

Park. During others, however, such as the storms of July, 1915, and March 15 to 18, 1919, which were fairly uniform throughout the Miami Valley, it is believed that the Dayton records furnish fairly reliable information regarding the Moraine Park intensities.

It is also possible that a study of the excessive precipitation, as tabulated from the graphical records and published in the Monthly Weather Review, in connection with a study of the occurrence of runoff on the bare soil plats may throw some light on the capacity of the soil to absorb precipitation during intense showers. "Excessive precipitation" is a term used by the U. S.

Weather Bureau to denote intensities amounting to or exceeding the following rates:

Inches	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.80
In min.	5	10	15	20	25	30	35	40	45	50	60

Studies of rates of rainfall and of percolation or absorption have been made for some of the storms for which it is believed that the graphical records may be safely used. The rates of rainfall in inches per hour at Moraine Park were first platted as illustrated in figures 9 and 10. In determining the intensities

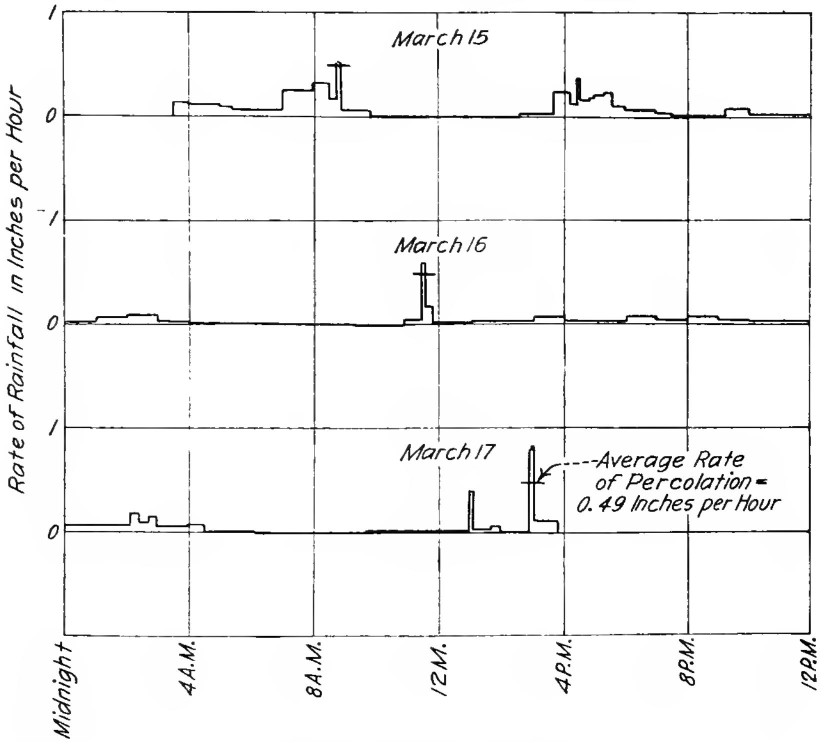

FIG. 10.—RATE OF RAINFALL AT MORAINE PARK DURING STORM OF MARCH 15 TO 17, 1919.

The average rate of percolation indicated by the horizontal line cutting through the periods of most intense precipitation, applies only to the bare soil plats.

at the plats from the Dayton records it was assumed that the rates of precipitation at the two places for short periods of time were in the same proportion as the total amounts for the storm period. While this assumption may be somewhat in error at

times, it is the only possible basis upon which to proceed. Moreover no storms have been studied where the intensities at the two locations could have been appreciably different.

The rates of precipitation were calculated for short intervals of time, by dividing the length of the interval in hours into the total rainfall in inches. In general, 5-minute intervals were used where the precipitation was excessive, and longer intervals where the rates were not so intense. Although the rates varied during the intervals used, they were platted as if they had been constant. This method is sufficiently accurate for the present purpose and has the advantage that the area under the diagram is kept exactly equal to the total precipitation from which the rates were calculated.

If it is assumed that the runoff occurred during the periods of most intense precipitation, that the amount of water evaporated during these periods was negligible, and that water entered the ground at a uniform rate at such times; then this rate of absorption, or of percolation, as the case may be, will be represented on the diagram by a horizontal line at such a height that the total area enclosed between it and the line representing the rate of precipitation will be equivalent to the total runoff. This rate would be the maximum mean rate at which water could soak into the bare soil under the conditions then existing. It would not, of course, be constant for the different storms, but would vary widely due to variations in temperature, condition of the surface, amount of soil moisture present, and rainfall intensity. In fact, it would probably vary considerably during a given storm. The assumption that it would be constant during the periods of most intense rainfall may be appreciably in error in certain cases. However, since continuous records of runoff were not secured, it is not possible to allow for such variations.

Maximum rates of absorption or of percolation were determined in the above described manner for the bare soil plats for several storms occurring during different seasons of the year. The studies for the storms of July 7, 1915, and March 15 to 17, 1919, are shown in figures 9 and 10. The rate at which the water entered the soil during the July storm has been termed "rate of absorption" since the soil was not saturated when the rain began or after it had ceased. For the March storm the rate has been termed "rate of percolation" since in this case the soil was practically saturated when the rain began, so that the

greater part of the water entering the soil must have percolated through the surface layer into the underlying sand and gravel.

The results of the studies are given in table 12. The amount of moisture in the soil under the bare surface when the rain began, the total precipitation, the total runoff, and the rates of absorption or of percolation are included for the various storms investigated. The storms are arranged in the table by dates according to the calendar year, irrespective of the year of their occurrence. The rates of percolation or absorption are the actual depths of water which would be taken up by the soil in one hour if the absorption rate existing during the period in which the runoff occurred continued that long.

A study of the data in table 12, of the rainfall distribution during the storms included in this tabulation, and of excessive rainfall records at Dayton, results in three conclusions regarding the bare soil plats at Moraine Park, as follows:

1. That water can percolate through the two-foot layer of surface soil into the underlying sand and gravel, when the ground is saturated but not frozen, at a rate as great as 0.25 of an inch per hour.

2. That water can be absorbed by the soil at times when the ground is unusually dry, at a rate as great as 1.00 inch an hour for intervals as long as 30 minutes.

3. That water cannot be absorbed by the soil at any time, no matter how dry it is, at a rate as great as 3.00 inches per hour for periods as long as 5 minutes.

Table 12.—Rainfall Intensities and Rates of Percolation and Absorption at Moraine Park

Storm	Moisture in Soil† when rain began in per cent	Total Precipitation in Inches	Total Average Runoff from Bare Soil in Inches	Average Rate* of Percolation or Absorption in Inches per hour
Mar. 15–17, 1919...	17.2	2.81	0.06	0.49
Mar. 26–27, 1916...	16.7	1.77	0.28	0.30
Apr. 9–10, 1919...	18.0	1.53	0.14	1.04
Apr. 30, 1917...	17.6	0.95	0.46	0.45
May 3– 7, 1916...	13.4	1.75	0.59	0.31
May 11–12, 1918...	15.8	2.75	0.85	0.27
July 7, 1915...	9.4	2.07	0.70	1.00
Sept. 5, 1915...	††14.3	2.15	0.32	0.40
Sept. 5– 6, 1916...	3.7	4.12	1.78	1.21

†Under bare surface.

*Depths of rainfall taken up by the soil per hour during the periods in which runoff occurred.

††Moisture content of soil on September 7.

The first conclusion was based primarily on a study of the storms of March 26 and 27, 1916, March 15 to 17, 1919, and April 30, 1917. The rate of 1.04 inches per hour, given for the storm of April 9 and 10, 1919, probably represents absorption rather than percolation. It is comparatively high due to the small amount of runoff together with the fact that the intense rates of percipitation occurred in three separate showers no one of which lasted more than five minutes.

The second conclusion was based on a study of the storms of July 7, 1915, and September 5 and 6, 1916. The records are unusually good for the former. This storm was fairly uniform throughout the valley, in intensity as well as in duration. For the latter it is believed that the absorption rate is too high due to the runoff being too low. The absorption rate for the storm of September, 1915, appears to be low although no satisfactory reason can be offered.

The third conclusion was based on a study of the excessive precipitation at Dayton, as tabulated and published by the U. S. Weather Bureau, together with the data given in table 3. It was found that some water ran off of the bare soil plats on all but one of the 31 dates on which excessive rates of precipitation occurred at Dayton. The storm in which no runoff occurred was one in which the total precipitation amounted to 0.80 inches at Dayton and only 0.07 inches at the plats, so that the intensities at the two places were not at all comparable.

Some interesting observations on rainfall intensities and runoff conditions were obtained in Dayton on April 20, 1920, when the soil was already practically saturated. A heavy shower occurring during the period from 6:30 to 6:41 a. m. caused considerable runoff from bare soil and sod surfaces, both level and sloping. The total precipitation during this time was 0.23 of an inch, corresponding to an average rate of precipitation of 1.25 inches per hour. During the period from 7:20 a. m. to 7:30 a. m., when the average rate of precipitation was 0.54 of an inch an hour, no runoff whatever could be noticed on either bare soil or sod surfaces even on comparatively steep slopes. These observations would indicate that water can be taken up by the soil, when the ground is practically saturated, at a rate as great as a half an inch an hour but that it cannot be taken up at a rate as great as an inch and a quarter an hour.

The rate at which water can enter the ground varies widely with the composition and texture of the soil, its temperature.

the type of surface covering, the amount of moisture present, and the rainfall intensity. Much has been written on the movements of soil moisture. To attempt any general discussion of the matter is beyond the scope of this publication. It may be stated, however, that the effect of initial moisture content on the rate of movement was discussed in the Journal of Agricultural Research, July 16, 1917, by F. S. Harris and H. W. Turpin.* The rate of movement was shown to increase as the initial amount of moisture present increased. It may be mentioned also that Professor King of Wisconsin University found that water would percolate through a column of clay loam 14 inches long at a rate of 1.6 inches depth in 24 hours.** However, as he did not give a mechanical analysis of the soil, it is not possible to compare his result with the rate at which water will move through the Moraine Park soil.

Conditions During Storm Periods

Table 13 contains the rainfall and runoff data for all of the large storms which occurred during the period covered by the records. The dates of the storm periods, the total precipitation, the total average runoff from each type of surface covering, the rainfall which did not run off, or the retention as it is termed, and the ratios of the runoff to the rainfall, in per cent, are included for each storm. In a few cases, where observations had not been made just before and just after the given periods, the total rainfall was calculated from the Dayton daily records, assuming that the ratio of the precipitation during the storm to the total observed was the same at both locations. This was only done in instances where it was known from a study of other data that appreciable errors could not result.

The storms are arranged in the table in groups. Those in which the precipitation occurred in one day or less, called one-day storms, are included in the first group; those in which the precipitation covered a period of more than one day and not more than two days, called two-day storms, are included in the second, and so on. In each group storms are arranged chronologically. Only those storms have been included in which the rainfall amounted to or exceeded 1.00 inch in one day, 1.50 inches

*Movement and Distribution of Moisture in the Soil, by F. S. Harris and H. W. Turpin, Journal of Agricultural Research, U. S. Department of Agriculture, July 16, 1917.

**The Soil, Its Nature, Relations, and Fundamental Principles of Management, by F. H. King, 1906, page 171.

Table 13.—Rainfall, Runoff, and Retention at Moraine Park During Storm Periods

Storm Period	Total Rainfall in Inches	Average Runoff in Inches		Retention in Inches		Ratio of Runoff to Rainfall, in %	
		Sod	Bare	Sod	Bare	Sod	Bare
ONE-DAY STORMS							
May 20, 1915	1.15	0	0	1.15	1.15	......	......
May 30, 1915	1.22	0.01	*0.18	1.21	1.04	0.8	14.7
June 2, 1915	1.14	0.02	0.25	1.12	0.89	1.8	21.9
June 15, 1915	1.10	0.01	0.13	1.09	0.97	0.9	11.8
July 7, 1915	2.07	0.24	0.70	1.83	1.37	11.6	33.8
Sept. 5, 1915	2.15	0	0.32	2.15	1.83	......	14.9
June 2, 1916	1.99	0.02	*1.15	1.97	0.84	1.0	57.8
Sept. 5–6, 1916	4.12	0.02	*1.78	4.10	2.34	0.5	43.2
Jan. 5, 1917	2.04	0	0.72	2.04	1.32	......	35.3
Mar. 13, 1917	1.31	0.10	0.58	1.21	0.73	7.6	44.3
July 7, 1917	1.25	0.01	0.30	1.24	0.95	0.8	24.0
Oct. 18, 1917	1.29	0.01	0.54	1.28	0.75	0.8	41.9
Oct. 29, 1917	1.14	0	0.55	1.14	0.59	......	48.2
May 12, 1918	2.23	0.02	0.85	2.21	1.38	0.9	38.1
June 6, 1918	1.32	0	0.28	1.32	1.04	......	21.2
Aug. 12, 1918	1.21	0.02	0.66	1.19	0.55	1.7	54.5
July 20, 1919	1.66	0.01	0.10	1.65	1.56	0.6	6.0
Aug. 24, 1919	2.56	0.17	1.72	2.39	0.84	6.6	67.2
TWO-DAY STORMS							
May 20–21, 1915	1.59	0	0.04	1.59	1.55	......	2.5
June 1–2, 1915	2.01	0.02	0.36	1.99	1.65	1.0	17.9
Sept. 26–27, 1915	1.82	0.01	0.10	1.81	1.72	0.5	5.5
Nov. 18–19, 1915	1.55	0.01	0.01	1.54	1.54	0.6	0.6
Mar. 26–27, 1916	1.77	0.01	0.28	1.76	1.49	0.6	15.8
Sept. 27–28, 1916	1.61	0	0	1.61	1.61	......	......
June 27–28, 1917	2.67	0.02	*1.70	2.65	0.97	0.7	63.6
Aug. 21–22, 1917	2.95	0.02	1.44	2.93	1.51	0.7	48.8
Oct. 18–19, 1917	1.56	0.01	1.54	1.55	1.02	0.6	34.6
May 11–12, 1918	2.75	0.02	0.85	2.73	1.90	0.7	30.9
July 22–23, 1918	3.11	0.07	2.22	3.04	0.89	2.3	71.4
Apr. 9–10, 1919	1.53	0.02	0.14	1.51	1.39	1.3	9.1
May 8–9, 1919	1.57	0.01	0.11	1.56	1.46	0.6	7.0
Oct. 26–27, 1919	2.19	0.02	0.48	2.17	1.71	0.9	21.9
THREE-DAY STORMS							
May 20–22, 1915	2.02	0.04	0.19	1.98	1.83	2.0	9.4
Jan. 10–12, 1916	2.52	0.09	0.22	2.43	2.30	3.6	8.7
Aug. 4–6, 1916	2.51	0.12	1.26	3.39	2.25	3.4	35.9
May 26–28, 1917	2.28	0.01	0.90	2.27	1.38	0.4	39.5
July 22–24, 1918	3.68	0.07	2.33	3.61	1.35	1.9	63.3
Mar. 15–17, 1919	2.81	0.02	0.06	2.79	2.75	0.7	2.1
May 7–9, 1919	2.19	0.01	0.33	2.18	1.86	0.5	15.1
FOUR-DAY STORMS							
Aug. 4–7, 1916	3.63	0.12	1.26	3.51	2.37	3.3	34.7
Mar. 15–18, 1919	2.94	0.02	0.06	2.92	2.88	0.7	2.0
FIVE-DAY STORMS							
Aug. 4–8, 1916	4.56	0.13	1.28	4.43	3.28	2.9	28.1

*Record probably low.

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in two consecutive days, 2.00 inches in three consecutive days, and so on, increasing 0.50 of an inch for each additional day. Records have been included for both types of surface covering whenever the above criterion was satisfied for one type. No storms satisfying this criterion for periods longer than five days occurred during the time covered by the data. The maximum values of the various quantities are indicated as in preceding tables. Storms in which the precipitation occurred as snow have not been included.

One-day Storms

Considering the one-day storms, an examination of the data in table 13 shows that the storm of September 5 and 6, 1916, was the one in which the rainfall was greatest. While this storm is included in the one-day group, the total precipitation of 4.12 inches actually occurred in about eight hours. About 88 per cent of the total fell in four separate showers in the afternoon and evening of the fifth and on the morning of the sixth, in a total time of one and three-quarters hours. This storm occurred when the ground was unusually dry, when there was a fairly heavy growth of grass on the sod plats, and when the weather conditions were favorable for high rates of evaporation. On the sod plats, where considerable surface storage was available, only 0.02 of an inch ran off, the remaining 4.10 inches, the maximum value of the retention for the one-day storms, being taken up by the soil or evaporated between showers. This value of 4.10 inches, or practically the entire precipitation, is greater than the maximum corresponding values for the two, three, and four-day storms, being exceeded only by the value of 4.43 inches for the one five-day storm. On the bare soil plats, where there was no surface storage, 1.78 inches, or about 43 per cent of the rainfall, ran off. This is the maximum value of the runoff for the one-day periods. However, the precipitation during this storm was so great that in spite of the relatively large amount of runoff, the retention for the bare soil, 2.34 inches, or about 57 per cent of the rainfall, was not only the maximum value for the one-day storms, but was also greater than any of the two-day values.

The maximum amount of runoff from the sod plats, for the one-day periods, occurred during the storm of July 7, 1915. This was an intense storm of about an hour's duration, as shown in figure 9. The runoff amounted to 0.24 of an inch or to about 11.6 per cent of the rainfall, this value of the ratio of runoff

to rainfall also being the maximum for the one-day storms. In fact, the runoff from the sod and its ratio to the total precipitation were both greater than during any of the other storms included in table 13. The soil was neither unusually dry nor unusually wet when the rain began. The sod was covered with a fairly large growth of grass so that considerable surface storage was available.

The maximum ratio of the runoff to the rainfall for the bare soil plats, 67.2 per cent, occurred during the intense storm of August 24, 1919. This storm occurred at a time when the soil contained more than the ordinary amount of moisture.

The greater number of the one-day storms occurred during the summer and fall months. Of the eighteen storms included in this group, sixteen occurred during the months of May to November, inclusive. Only two, the storms of January 5 and March 13, 1917, occurred during the months of December to April, inclusive. During the storm of January 5, 1917, in which the rainfall amounted to 2.04 inches, there was no runoff, whatever, from the sod plats, and only 0.72 of an inch, or about 35 per cent of the rainfall, from the bare soil plats; so that the retention amounted to 2.04 and 1.32 inches, respectively for the two types of surface cover. During the storm of March 13, 1917, in which there was only 1.31 inches of rain, the runoff amounted to 0.10 of an inch, or about 7.6 per cent of the rainfall, in the case of the sod, and to 0.58 of an inch, or about 44 per cent of the rainfall, in the case of the bare soil. During this storm the values of the retention were 1.21 and 0.73 inches, respectively, for the two types of surface covering. Both of these storms occurred at times when the soil was saturated and contained no frost.

Two-day Storms

Considering the two-day storms the maximum values of the rainfall, of the runoff, and of the ratio of runoff to rainfall for both types of surface cover, and of the retention for the sod, occurred during the storm of July 22 and 23, 1918. The maximum value of retention for the bare soil occurred during the storm of May 11 and 12, 1918, amounting to 1.90 inches, or about 69 per cent of the total rainfall of 2.75 inches. During the July storm the rainfall was 3.11 inches; the runoff from the sod, 0.07 of an inch, or about 2.3 per cent of the rainfall; the retention for the sod, 3.04 inches, or about 98 per cent of the rainfall; the

runoff from the bare soil, 2.22 inches, or about 71 per cent of the rainfall; and the retention for the bare soil, 0.89 inches, or about 29 per cent of the rainfall. During the May storm the runoff from the bare soil amounted to only 0.85 of an inch, or about 31 per cent of the rainfall. The July storm occurred when the soil was unusually dry. The May storm occurred when the ground was practically saturated. The fact that the runoff from the bare soil during the July storm, when the ground was dry, was much greater than during the May storm, when the soil was practically saturated, is explained by a consideration of the intensities of the precipitation during the two storms, the intensities during the July storm being much greater than during the May storm.

It will be noticed that in this group, also, the greater number of storms occurred during the summer and fall months. Of the fourteen two-day storms, twelve occurred during the months of May to November, inclusive. Only two, the storms of March 26 and 27, 1916, and April 9 and 10, 1919, occurred during the months of December to April, inclusive. These two storms occurred when the upper foot of soil was practically saturated. During the March storm, the greater of the two, the rainfall was 1.77 inches; the runoff, 0.01 of an inch, or about 0.6 per cent of the rainfall, in the case of the sod, and 0.28 of an inch, or about 16 per cent of the rainfall, in the case of the bare soil; the retention 1.76 inches, or practically the entire rainfall, in the case of the sod, and 1.49 inches, or about 84 per cent of the rainfall, in the case of the bare soil.

Three-day Storms

In studying the three-day storms it will be noticed that the maximum values of the various quantities were distributed among four of the seven storms. The maximum values of rainfall, of runoff from the bare soil, of ratio of runoff to rainfall for the bare soil, and of retention for the sod, occurred during the storm of July 22 to 24, 1918. This storm was the one which gave the maximum two-day values. For the three-day period the rainfall amounted to 3.68 inches, a value greater than either of the storms included in the four-day group; the runoff, to 0.07 of an inch, or about 2 per cent of the rainfall, in the case of the sod, and to 2.33 inches, or about 63 per cent of the rainfall, in the case of the bare soil; and the retention to 3.61 inches, or about 98 per cent of the rainfall, in the case of the sod, and to 1.35

inches, or about 37 per cent of the rainfall in the case of the bare soil. The maximum absolute value of the runoff from the sod occurred during the storm of August 4 to 6, 1916, amounting to 0.12 of an inch, or about 3.4 per cent of the rainfall. This storm occurred when the soil was dryer than at any other time during the four and a half years covered by the data. The maximum value of the ratio of the runoff to the rainfall for the sod occurred during the storm of January 10 to 12, 1916, amounting to 3.6 per cent. The maximum value of the retention for the bare soil occurred during the storm of March 15 to 17, 1919, amounting to 2.75 inches, or to practically the entire rainfall. The comparatively small amount of runoff during this storm, only 0.06 of an inch, was due to the comparatively low rates of precipitation, see figure 10. Although the ground was practically saturated at the time, the intensities of precipitation were so low that the water could percolate through the surface soil into the sand and gravel as fast as it fell.

Only two of the seven storms included in this group fell during the months of December to April, inclusive, these two being the storms of January, 1916, and March, 1919, mentioned above. Of the remaining five, three were in May, one in July, and one in August.

Four-day Storms

Only two four-day storms appear in the table. These are the storms of August 4 to 7, 1916, and March 15 to 18, 1919, the three-day periods of which were discussed above. The retention for the bare soil during the March storm, 2.88 inches, or about 98 per cent of the rainfall, is the only quantity in this group which was not exceeded during some one of the preceding one, two, or three-day storms.

Five-day Storms

The only storm appearing in this group is the storm of August 4 to 8, 1916, the three and four-day periods of which are also included in the table. The total rainfall for the five-day period amounted to 4.56 inches. The total runoff, however, amounted to only 0.13 inches, or to about 3 per cent of the rainfall, in the case of the sod; and to only 1.28 inches, or to about 28 per cent of the rainfall in the case of the bare soil. The runoff was comparatively small due to the comparatively low rates of rainfall and due to the fact that the soil was unusually dry. The retention amounted to 4.43 inches, or about 97 per cent of

the rainfall, in the case of the sod; and to 3.28 inches, or about 72 per cent of the rainfall, in the case of the bare soil.

ANNUAL SURFACE RUNOFF

Table 14 contains the total precipitation, the total surface runoff from each type of surface cover, and the ratio of surface runoff to rainfall, for each year for which records are available. Maximum and minimum values are indicated as in preceding tables. Averages of the various quantities are given at the bottom of the table, although the four-year record is, of course, too short to give reliable averages. The quantities were calculated for the year ending September 30, in each case, since that is the year generally used in tabulating stream flow records in this part of the United States.

An examination of table 14 shows that the minimum values of annual surface runoff occurred in the year ending September 30, 1919, amounting to 0.40 inches for the sod and to 5.64 inches for the bare soil; and that the maximum values occurred in the

Table 14.—Annual Surface Runoff and Rainfall at Moraine Park

Year Ending September 30	Total Surface Runoff in Inches		Total Rainfall in Inches	Ratio of Surface Runoff to Rainfall, in per cent		
	Sod	Bare		Sod	Bare	Average
1916	.85	6.52	**44.72**	1.9	**14.6**	8.2
1917	.88	9.15	37.59	2.3	24.4	13.4
1918	**2.82**	**12.99**	38.27	**7.4**	**34.0**	**20.7**
1919	**.40**	**5.64**	**35.77**	**1.1**	15.8	8.4
Average	1.24	8.58	39.09	3.2	22.2	12.7

preceding year, amounting to 2.82 inches for the sod and to 12.99 inches for the bare soil. The average value of the ratio of runoff to rainfall for the two types of surface covering was 8.4 per cent in 1919 and 20.7 per cent in 1918. A value of 8. 2 per cent, or 0.2 of a per cent less than the 1919 value, occurred in 1916. The average for the four years was 12.7 per cent. The average annual surface runoff was 1.24 inches for the sod and 8.58 inches for the bare soil, averaging 4.91 inches. The average annual rainfall for the four years was 39.09 inches or slightly more than the mean annual value of 38.14 inches determined for the Dayton station from a 36-year record.

If it is assumed that the average annual runoff from the Moraine Park areas, including the ground water flow as well as

the surface runoff, is one-third of the average annual rainfall, or 13.0 inches, an assumption which will be corroborated in a later chapter, the average annual value of the ground water flow, or percolation, for the two types of surface cover, is found to be about 8.1 inches. That is, the annual surface runoff is about 12.5 per cent, and the annual percolation, about 20.7 per cent of the annual rainfall.

SUMMARY

The principal conclusions reached from the studies of the Moraine Park experiments may be summarized as follows:

1. That the surface soil, which extends only to a depth of about 2 feet, weighs about 100 pounds per cubic foot, in place, when dry.

2. That the soil when saturated contains an amount of moisture equal to about 41 per cent of the volume, or about 25 per cent of the dry weight of the soil.

3. That during the dryest times of the summer the 2-foot depth of soil never contains less than from 3 to 4 per cent of moisture, by weight.

4. That the moisture holding capacity of the 2-foot layer of soil is about 21 per cent by weight.

5. That the soil is generally dryest in the late summer or early fall, during the months of July, August, or September; and wettest in the late winter or early spring, during the months of January, February, or March.

6. That the amount of moisture in the soil gradually increases in the fall, during the months of October, November, and December; that it does not change much during the winter months, even in the absence of rainfall; and that it begins to diminish appreciably in the spring, during the months of April or May.

7. That the upper 2 feet of soil seldom, if ever, becomes filled with capillary water during the months of June, July, or August, even though the rainfall is considerably greater than normal.

8. That variations in the amount of soil moisture for short periods of time are much greater in the summer than in the winter.

9. That during the summer, rates of evaporation from bare soil and of transpiration and evaporation from sod surfaces, may be as great as a half an inch per day for periods as long as five days.

10. That during the months of January and February soil

evaporation, under the most favorable conditions, does not amount to more than from 0.02 to 0.05 of an inch per day.

11. That the average rate of evaporation from snow surfaces during the period from December 3, 1917, to February 11, 1918, was about 0.023 inches per day.

12. That the actual amount of moisture in the upper 2 feet of soil is equivalent to a depth of about 1.5 inches when the soil is dryest, and to a depth of about 8 inches when the soil contains the maximum amount of capillary water, the difference in the two amounts being about 6.5 inches.

13. That the difference between the amount of water in the upper 2 feet during the ordinary dry periods of the summer and the amount present during the winter is about 5 inches.

14. That the amount of water absorbed by the upper 2 feet during individual storms was greatest during the storm of August 4 to 8, 1916, amounting to about 4.0 inches, the total precipitation being 4.56 inches.

15. That the amount of water absorbed by the upper 2 feet during a given storm is greater under sod surfaces than under bare soil surfaces.

16. That for extremely small areas, such as the Moraine Park plats, the occurrence and amount of runoff are affected much less by surface slope than by surface cover.

17. That appreciable surface runoff frequently occurs during intense summer storms when the upper 6 inches of soil are not nearly saturated.

18. That surface runoff does not occur during some less intense storms even though the ground is saturated.

19. That water can percolate through the 2-foot layer of surface soil on the bare soil plats at Moraine Park, when the ground is saturated but not frozen, at a rate as great as 0. 25 of an inch per hour.

20. That water can be absorbed by the bare soil at times when the soil is unusually dry, at a rate as great as 1.00 inch per hour for intervals as long as 30 minutes.

21. That water cannot be absorbed by the bare soil at any time, no matter how dry it is, at a rate as great as 3.00 inches per hour for periods as long as 5 minutes.

22. That the maximum values of the retention during summer storms covering periods of 1, 2, 3, 4, and 5 days amounted to 4.10, 3.04, 3.61, 3.51, and 4.43 inches, respectively, in the case

of the sod plats, and to 2.34, 1.90, 2.25, 2.37, and 3.28 inches, respectively, in the case of the bare soil plats.

23. That similar values for winter storms for periods of 1, 2, 3, and 4 days amounted to 2.04, 1.76, 2.79, and 2.92 inches, respectively, in the case of the sod plats, and to 1.32, 1.49, 2.75, and 2.88 inches, respectively, in the case of the bare soil plats. However the values of retention for the winter storms are not directly comparable with those for the summer storms owing to differences in precipitation.

24. That the annual surface runoff at Moraine Park amounts to about one-eighth of the rainfall and that the annual percolation amounts to about one-fifth of the rainfall.

CHAPTER IV.—SPRINKLING EXPERIMENTS

In the summer of 1920 experiments on rainfall and runoff were undertaken in which rainfall effects were produced artificially by sprinkling. The work was begun at the Moraine Park plats with the object of developing a method by which rainfall and runoff relations could be determined for a given watershed, without waiting the comparatively long time required for the accumulation of sufficient records from natural rainfall. This object was accomplished in the first experiments. It was found that the sprinkling method was practicable and that the results obtained agreed with the data previously collected. It was then decided to continue the experiments at Moraine Park and also to conduct similar experiments at other places in the Miami Valley where different soil conditions existed. The object of continuing the experiments was to secure data on runoff and retention during unusually heavy rainstorms, such as those for which the Miami Valley flood prevention works are designed; and also to secure data for use in studying the general relations between rainfall and runoff.

DESCRIPTION OF PLATS

The Moraine Park plats have been fully described in the preceding chapter. Four additional plats were established at the Taylorsville Dam; two in the bottom of the valley, where the surface soil is a rich black alluvial deposit underlaid by glacial till, and two on the top of the hill near the west end of the Dam, where the surface soil is a compact yellow clay till. Two plats were established at each place so that two experiments could be run without waiting for the soil to dry out. The plats on the hill were located in an alfalfa field where the growth was comparatively thin. Those in the valley were located near the commissary gardens where a rather heavy growth of weeds had just been removed and where the soil had not been cultivated for a year or more.

The black soil in the valley extends to a depth of about two feet. For depths of from two to about eight feet the material is a yellow clay till somewhat similar to that on the hill. Below

a depth of eight feet the material is almost entirely sand and gravel. At the hill plats the yellow till extends to depths of twenty-five feet or more, and varies but little at the different depths. Some humus is present in the surface foot at each location. Table 15 gives the results of soil analyses made by the Bureau of Soils, U. S. Department of Agriculture.

Table 15.—Mechanical Analyses of Taylorsville Soils Made by Bureau of Soils, U. S. Department of Agriculture

Sample Number	Depth below Surface Feet	Percentages of Soil particles of following diameters in mm.						
		2-1	1-0.5	0.5-0.25	0.25-0.10	0.10-0.05	0.05-0.005	0.005-0
		PLATS 1 AND 2						
1	1.0	0.8	1.8	2.0	6.3	13.5	50.0	25.9
2	1.5	1.2	3.1	2.3	13.6	9.6	45.7	24.4
3	2.0	0.8	1.8	1.6	9.6	9.8	50.4	26.0
4	2.5	0.0	1.3	1.1	8.0	8.6	56.2	24.9
5	3.0	0.0	0.0	1.5	6.7	8.8	60.0	23.0
6	3.5	0.0	0.6	0.7	9.2	10.8	56.4	22.2
7	4.0	0.0	0.8	1.7	20.5	13.8	42.2	21.1
8	4.5	1.9	6.1	3.5	20.6	14.9	32.0	20.9
9	5.0	1.6	3.2	2.1	16.4	11.2	38.0	27.4
10	5.5	7.0	11.2	2.5	9.3	13.2	33.7	23.0
		PLATS 3 AND 4						
11	0.5	1.0	0.8	1.1	7.0	8.3	50.2	31.5
12	1.0	1.1	3.0	1.9	11.4	9.5	38.0	35.0
13	1.5	0.8	3.0	2.2	14.5	13.5	34.2	31.8
14	2.0	1.8	4.4	2.5	12.2	14.2	38.2	26.9
15	2.5	2.8	7.1	3.5	13.3	15.3	38.0	19.9
16	3.0	2.5	6.1	3.6	13.3	14.3	42.3	18.2
17	3.5	3.1	6.2	3.6	13.2	14.6	39.4	20.2
18	4.0	3.5	6.2	3.4	13.9	13.8	39.1	20.5
19	4.5	4.3	7.0	3.7	14.0	14.6	39.2	17.0
20	5.0	3.4	6.4	3.5	13.8	15.3	38.2	19.5

In the valley the ground surface is practically level, the slopes being only great enough to cause the water to drain toward the tile outlets. On the hill the surface slopes toward the outlets at a rate of about 0.5 feet in 10 feet.

Figure 11 shows the valley plats and figure 12 shows the hill plats, plats being numbered consecutively for convenience in the following discussions. Each plat is 5 feet square, as at Moraine Park. It will be noticed that some vegetation is present in plat 1, in the valley, and in both plats on the hill. Plat 2, in the valley, was spaded to a depth of about 6 inches and then raked so as to correspond to a corn field after planting and dragging.

The plats were separated from the adjacent land by galvanized sheet iron boundaries extending about 4 inches above the

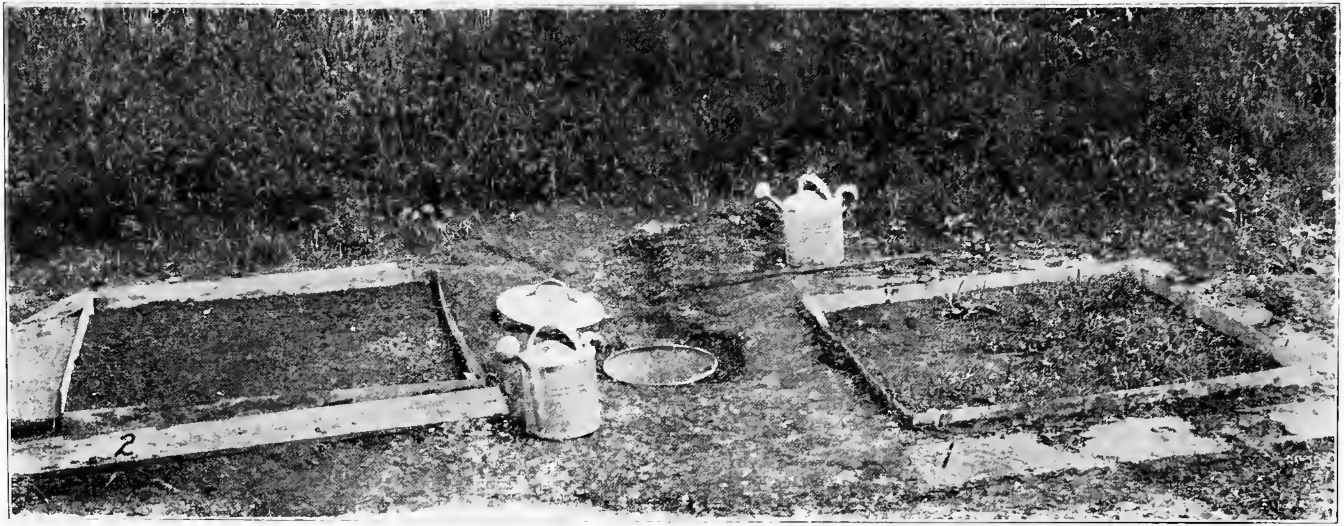

FIG. 11.—EXPERIMENTAL PLATS 1 AND 2 AT THE TAYLORSVILLE DAM.

These plats are located in the bottom of the valley where the surface soil is a rich black alluvial deposit. Note the sprinkling cans used in reproducing rainfall effects.

ground and about 20 inches below. The corners were soldered so as to be water-tight. In setting the boundaries care was taken not to disturb the areas within the plats, the trenches being dug entirely on the outside of the plats and with vertical smooth walls on the sides where the sheet iron was to be set. After setting the boundaries to the required depth the trenches were carefully backfilled and puddled so as to be as nearly water-tight as possible.

Tanks to catch the runoff were set between the plats at each location, as shown in the figures, and were connected to the plats by 3-inch sewer pipe. Care was taken to obtain water-tight joints where the pipe pass through the boundaries. One tank was sufficient for both plats in each case, since only one plat was to be experimented on at a time. The tanks were provided with covers so that they could be kept covered when experiments were not being made.

METHODS OF EXPERIMENTATION

Water was applied with the two garden sprinkling cans shown in figure 11, in all experiments except the first, when only one can was available. The cans are identical in capacity as well as in size and number of nozzle openings. In running the experiments they were filled to marks previously located, at which the capacity of the can is equivalent to a depth of 0.20 of an inch over one of the plats. The cans were marked "A" and "B" for convenience in recording the data. The amount of precipitation was determined by recording the number of cans applied, and the rate of precipitation was obtained by recording the time required to empty them. Different rates of precipitation were obtained by plugging different numbers of nozzle openings.

The amount of runoff was determined by measuring the depth of water in the tank, and the rate of runoff was obtained by noting the time required for the tank to fill to the different depths. The gage used in measuring the depths is shown in figure 11. It was made by fastening two rain gage measuring sticks on to a small rod. Depths were measured to the nearest tenth of an inch and observations were made every three or four minutes.

In running experiments one man sprinkled while another filled the empty can, measured depths in the tank, and recorded the necessary data. The general procedure was to apply water at a constant rate until the surface became saturated, and then

to vary the rate of application through a range corresponding to actual rainfall conditions. The plat was then allowed to dry out to its original condition before a second experiment was run.

A split-second stop watch was used in determining time. Although it gave a little greater precision than was necessary, it was more convenient to use than an ordinary watch. Times were observed and recorded to the nearest second.

Soil samples, for determining the amount of moisture in the ground when the experiments were started, were taken from places just outside the plats. Samples were not taken after the experiments were finished since it would have been necessary to take them from within the plats. It was desired to keep the soil within the plats undisturbed so that subsequent experiments could be made with similar soil conditions. Experiments were not repeated on a given plat until a sufficient time had elapsed for the moisture content of the soil within the plat to become equal to that of the soil just outside.

In addition to the rainfall and runoff experiments conducted on the plats, a few supplementary experiments were made on areas lying near the plats, for the purpose of determining how long different rates of rainfall must continue before runoff begins. These experiments were made by marking off areas similar in size and in surface characteristics to the areas within the plats and then sprinkling them at different rates until runoff began. The time elapsing between the beginning of the sprinkling and the beginning of the runoff was observed for each rate of application.

RESULTS OF EXPERIMENTS

The results of the different experiments are given in tables 16 to 19, inclusive. Tables 16 and 17 give the rainfall, retention, and runoff data obtained at the Moraine Park and Taylorsville plats, respectively, arranged by runs; table 18 gives the total rainfall, runoff, and retention for the various experiments; and table 19 gives the data on the conditions necessary for runoff to begin, obtained during a few special runs made at various locations.

In tables 16 and 17 the total sprinkling time in hours; the total rainfall, retention, and runoff, in inches; and the average rates of rainfall, retention, and runoff, in inches per hour, are given for the various runs in which the experiments were conducted. The total quantities for each experiment, or series of

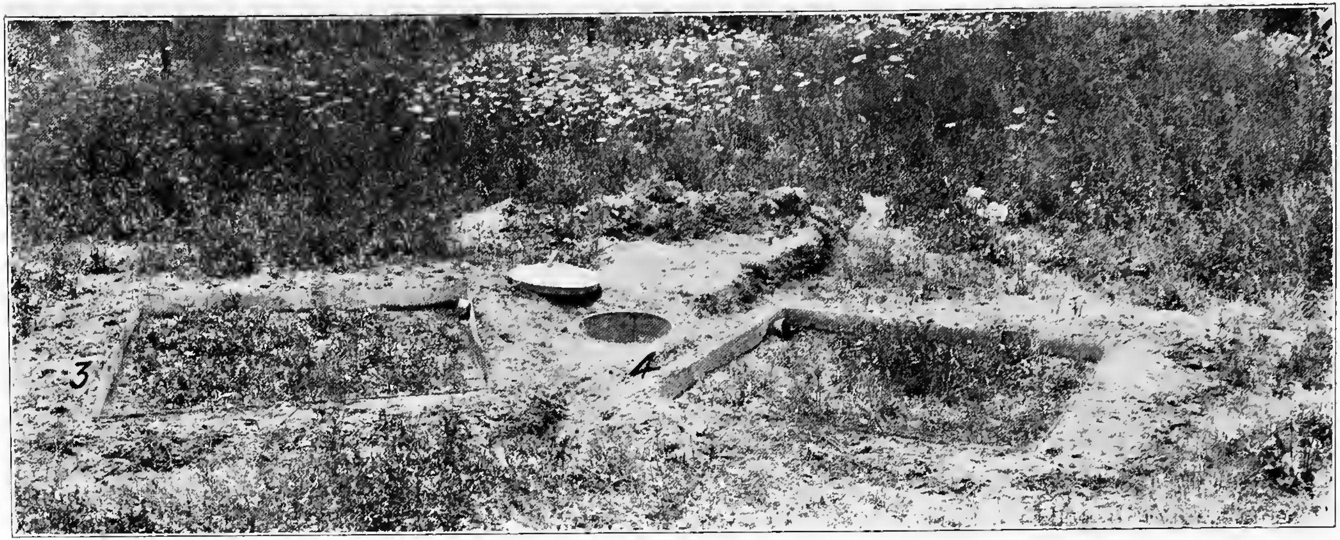

FIG. 12.—EXPERIMENTAL PLATS 3 AND 4 AT THE TAYLORSVILLE DAM.

These plats are located on the top of the hill at the west end of the dam where the soil is a compact yellow clay till.

runs, are given immediately following the last run of the series. Columns are also included giving the experiment number, the run number, the date, the time between successive runs on the same day, or on consecutive days, in hours and minutes, the ratio of total runoff to total rainfall in per cent, the average rate of sprinkling in inches per hour before runoff began, the time in minutes before runoff began, the total precipitation before runoff began, and the condition of the plats when the experiments were started.

For runs 1 to 8, inclusive, and runs 23 and 24, given in table 16, where the water was applied with one sprinkling can, the time of sprinkling is the net time, not including the intervals required to fill the can. The rate of runoff was computed by using the total net time in which runoff occurred, and the rate of retention was obtained by assuming the time in which the retention took place to be the same as the total sprinkling time. Consequently the differences between the rates of precipitation and runoff are not exactly equal to the rates of retention. It might have been better to have computed the rates of runoff and retention in a slightly different manner but since these experiments were more or less of a preliminary nature the data has not been recalculated.

The sprinkling was continuous during all of the remaining runs of table 16 and during all runs of table 17. For these runs slightly different methods of compilation were used. In calculating the average rate of runoff for a given run the short periods of time at the beginning and ending of the run, in which the rate of runoff was changing greatly, were not considered. The rate of retention was obtained by simply subtracting the rate of runoff from the rate of rainfall.

In all instances the total time given for a certain experiment, or series of runs, is the actual time from the beginning of the first run to the end of the last run, including nights as well as other intervening periods, rather than the total of the sprinkling times for the runs included in the experiment. For runs 1 to 8, inclusive, in table 16, a second set of totals is given, in which are included the actual rainfall and runoff quantities which occurred during the evening of June 2.

In table 18 the total quantities for the different experiments are brought together so that they may be studied collectively. The total time from the beginning of the first run to the end of the last run in hours, the total sprinkling time in hours, the total

Table 16.—Results of Sprinkling Experiments at Moraine Park during 1920

Experiment	Run Number	Date	*Time between Runs in Hours and Minutes	Total Quantities				Ratio of Runoff to Rainfall in per cent	Average Rates			Before Runoff Began			Remarks
				Sprinkling Time in Inches	Rainfall in Inches	Retention in Inches	Runoff in Inches		Rainfall in Inches per Hour	Retention in Inches per Hour	Runoff in Inches per Hour	Average Rate of Sprinkling in Inches per Hour	Time in Minutes	Total Precipitation in Inches	
LEVEL BARE SOIL PLAT															
Experiment 1	1	6– 1	......	0.84	3.41	1.70	1.71	50	4.06	2.03	1.86	4.25	2.0	.14	Soil dry and loose when Run 1 was begun; moisture content probably 8 to 10 per cent. Sprinkling intermittent.
	2	6– 2	21–25	0.90	1.89	0.90	0.99	52	2.10	1.00	1.11	2.24	3.3	.12	
	3	6– 2	0–13	0.44	0.49	0.30	0.19	39	1.12	0.70	0.46	1.31	1.8	.04	
	4	6– 2	0– 6	0.21	0.17	0.12	0.05	29	0.81	0.56	0.44	0.81	4.2	.06	
	5	6– 3	18–15	0.86	0.66	0.38	0.28	42	0.77	0.44	0.36	0.88	4 5	.07	
	6	6– 3	0–49	0.68	0.19	0.18	0.01	5	0.27	0.26	0.04	0.27	29.9	.13	
	7	6– 3	0	0.31	0.06	0.06	0	......	0.18	0.18	0	No	Runoff		
	8	6– 3	0–10	0.26	0.82	0.25	0.57	70	3.11	0.93	1.75	3.27	0.6	.03	
	1–8	......	......	†46.7	7.69	3.89	3.80	49	......	......	......	......	......	......	
	‡1–8	......	......	......	8.70	4.26	4.44	51	......	......	......	......	......	......	
Experiment 3	9	7–22	......	1.10	3.60	0.95	2.65	74	3.26	0.70	2.56	3.65	5.5	.34	Soil trampled and packed by cattle after Run 8; dry and hard; moisture content probably about 8 to 10 per cent when Run 9 was begun. Sprinkling continuous.
	10	7–22	0–11	0.96	3.20	0.41	2.79	87	3.33	0.35	2.98	3.27	1.1	.06	
	11	7–22	1–58	0.91	3.20	0.35	2.85	89	3.54	0.38	3.16	3.40	1.5	.09	
	12	7–23	18–57	1.76	3.00	0.46	2.54	85	1.70	0.13	1.57	1.76	9.5	.28	
	13	7–23	1–22	1.35	1.20	0.22	0.98	82	0.89	0.12	0.77	0.94	4.7	.07	
	14	7–23	0– 1	0.74	0.40	0.05	0.35	87	0.54	0.06	0.48	......	0	0	
	15	7–23	0– 1	0.76	0.20	0.06	0.14	70	0.26	0.09	0.17	......	0	0	
	9–15	......	......	†30.7	14.80	2.50	12.30	83	......	......	......	......	......	......	

Table 16.—*Continued*

Experiment	Run Number	Date	*Time between Runs in Hours and Minutes	Total Quantities: Sprinkling Time in Hours	Total Quantities: Rainfall in Inches	Total Quantities: Retention in Inches	Total Quantities: Runoff in Inches	Ratio of Runoff to Rainfall in per cent	Average Rates: Rainfall in Inches per Hour	Average Rates: Retention in Inches per Hour	Average Rates: Runoff in Inches per Hour	Before Runoff Began: Average Rate of Sprinkling in Inches per Hour	Before Runoff Began: Time in Minutes	Before Runoff Began: Total Precipitation in Inches	Remarks
SLOPING BARE SOIL PLAT															
Experiment 4	16	7–28	......	1.25	4.00	1.31	2.69	67	3.20	0.90	2.30	3.00	3.5	.18	Soil dry and loose; moisture content probably 8 to 10 per cent when Run 16 was begun. Sprinkling continuous.
	17	7–28	1–59	1.05	3.60	0.84	2.76	77	3.41	0.72	2.69	3.27	0.9	.05	
	18	7–28	0–10	1.00	3.40	0.67	2.73	80	3.41	0.62	2.79	3.43	0.8	.05	
	19	7–29	17–20	2.18	4.00	1.04	2.96	74	1.84	0.46	1.38	2.18	2.2	.08	
	20	7–29	2– 1	1.32	1.20	0.48	0.72	60	0.91	0.33	0.58	0.92	2.0	.03	
	21	7–29	0– 1	0.72	0.40	0.21	0.19	48	0.55	0.28	0.27	......	0	0	
	22	7–29	0	0.73	0.20	0.18	0.02	10	0.28	0.23	0.05	0.28	4.7	.02	
	16–22	......	......	†29.9	16.80	4.73	12.07	72	......	......	......	......	......	......	
LEVEL SOD PLAT															
Experiment 2	23	6– 3	......	0.49	2.06	2.06	0	......	4.17	4.17	0	No Run Off			Soil dry and very loose; full of roots. Sprinkling intermittent during Runs 23 and 24.
	24	6– 3	0– 2	0.43	6.20	6.08	0.12	2	14.4	14.1	0.4	14.4	§42.2	§4.87	
	25	6– 3	0–18	0.17	3.40	2.23	1.17	34	20.4	13.0	7.4	20.4	1.5	0.53	
	23–25	......	......	†2.0	11.66	‡0.37	1.29	11	......	......	......	......	......	......	

§Includes amounts in Run 23.
*From end of preceding run to beginning of present run.
†Total time from beginning of first run to end of last run.
‡Including actual rainfall and runoff during evening of June 2.

Table 17.—Results of Sprinkling Experiments at Taylorsville Dam during 1920

Experiment	Run Number	Date	*Time between Runs in Hours and Minutes	Total Quantities				Ratio of Runoff to Rainfall in per cent	Average Rates			Before Runoff Began			Remarks**
				Sprinkling Time in Hours	Rainfall in Inches	Retention in Inches	Runoff in Inches		Rainfall in Inches per Hour	Retention in Inches per Hour	Runoff in Inches per Hour	Average Sprinkling Rate Inches per Hour	Time in Minutes	Total Precipitation in Inches	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
PLAT 1															
Experiment 5	1	8– 9	......	1.28	4.00	1.50	2.50	62	3.12	1.13	1.99	3.50	3.0	0.18	Soil dry and hard; moisture content probably about 10 per cent, when Run 1 was begun.
	2	8– 9	2–42	0.94	3.00	0.44	2.56	85	3.18	0.43	2.75	3.27	1.5	0.08	
	3	8– 9	0–16	0.99	3.00	0.36	2.64	88	3.02	0.33	2.69	3.35	1 0	0.06	
	4	8–10	17–09	1.78	3.00	0.93	2.07	69	1.69	0.50	1.19	1.64	4.0	0.11	
	5	8–10	1–38	1.36	1.20	0.49	0.71	59	0.88	0.32	0.56	0.84	4.5	0.06	
	6	8–10	0	0.77	0.40	0.24	0.16	40	0.52	0.31	0.21	......	0	0	
	7	8–10	0	0.72	0.20	0.19	0.01	5	0.28	0.26	0.02	......	0	0	
	1– 7	......	......	†29.9	14.80	4.15	10.65	72	......	......	......	......	......	......	
Experiment 9	8	10–19	......	1.74	6.00	2.25	3.75	62	3.46	1.07	2.39	3.69	7.0	0.43	Soil unusually dry and hard; moisture content about 7 per cent; a few cracks in surface within plat and along boundaries, when Run 8 was begun.
	9	10–19	1–53	0.93	3.00	0.64	2.36	79	3.23	0.55	2.68	3.00	2.5	0.12	
	10	10–19	0– 9	0.88	3.00	0.46	2.54	85	3.40	0.47	2.93	3.27	0.5	0.03	
	8–10	......	......	†5.7	12.00	3.35	8.65	72	......	......	......	......	......	......	
PLAT 2															
Experiment 6	11	8–11	......	1.88	7.00	4.77	2.23	32	3.73	2.24	1.49	3.90	22.0	1.43	Soil dry and loose; spaded to a depth of 6 inches and thoroughly raked; moisture content about 10 per cent, when Run 11 was begun.
	12	8–11	2–29	1.38	5.00	2.05	2.95	59	3.63	1.44	2.19	3.69	1.5	0.09	
	13	8–12	18–57	2.14	4.00	1.94	2.06	52	1.87	0.86	1.01	1.85	6.0	0.18	
	14	8–12	1–24	1.15	1.20	0.63	0.57	48	1.04	0.53	0.51	1.09	3.0	0.05	
	15	8–12	0– 1	0.69	0.40	0.28	0.12	30	0.58	0.39	0.19	0.57	5.0	0.05	
	16	8–12	0	0.57	0.23	0.21	0.02	9	0.41	0.35	0.06	......	......	......	
	11–16	......	......	30.8†	17.83	9.88	7.95	45	......	......	......	......	......	......	

Table 17.—*Continued*

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
PLAT 3															
Experiment 7	17	8–16	......	0.92	3.20	0.47	2.73	85	3.49	0.39	3.10	3.43	2.5	0.14	Soil dry and hard; moisture content about 12 per cent, when Run 17 was begun.
	18	8–16	2–29	0.99	3.40	0.28	3.12	92	3.43	0.21	3.22	3.43	2.0	0.11	
	19	8–16	0–15	1.01	3.40	0.18	3.22	95	3.36	0.17	3.19	3.43	1.0	0.06	
	20	8–17	17–49	2.11	4.00	0.66	3.34	84	1.90	0.29	1.61	1.92	2.5	0.08	
	21	8–17	1–38	1.19	1.20	0.28	0.92	77	1.01	0.21	0.80	1.04	2.5	0.04	
	22	8–17	0– 2	0.69	0.40	0.12	0.28	70	0.58	0.16	0.42	......	0	0	
	23	8–17	0	0.65	0.20	0.11	0.09	45	0.31	0.17	0.14	......	0	0	
	17–23	......	......	30.4†	15.80	2.10	13.70	87	......	......	......	......	......	......	
Experiment 11	24	10–22	......	1.31	2.00	1.30	0.70	35	1.53	0.95	0.58	1.43	17.5	0.30	Soil unusually dry and hard; moisture content about 7 per cent; a few cracks in surface within plat when Run 24 was begun.
	25	10–22	1–12	1.32	2.00	1.00	1.00	50	1.51	0.67	0.84	1.55	3 0	0.08	
	26	10–22	......	1.28	2.00	0.64	1.36	68	1.56	0.54	1.02	......	0	0	
	24–26	......	......	5.2 †	6.00	2.94	3.06	51	......	......	......	......	......	......	
PLAT 4															
Experiment 8	27	8–18	......	1.08	3.60	0.68	2.92	81	3.32	0.55	2.77	3.43	2.5	0.14	Soil dry and hard; moisture content about 12 per cent, when Run 27 was begun.
	28	8–18	0–17	0.94	3.20	0.37	2.83	88	3.40	0.37	3.03	3.43	1.0	0.06	
	29	8–18	1–45	0.95	3.20	0.37	2.83	88	3.38	0.34	3.04	3.35	1.0	0.05	
	30	8–19	19– 0	1.91	3.60	0.81	2.79	78	1.90	0.41	1.49	2.00	2.5	0.08	
	31	8–19	1–54	1.23	1.20	0.33	0.87	72	0.97	0.25	0.72	0.99	2.0	0.03	
	32	8–19	0	0.62	0.40	0.13	0.27	67	0.64	0.22	0.42	......	0	......	
	33	8–19	0	0.49	0.20	0.10	0.10	50	0.41	0.20	0.20	......	0	......	
	27–33	......	......	30.6†	15.40	2.79	12.61	82	......	......	......	......	......	......	
Experiment 10	34	10–21	......	1.33	4.80	1.56	3.24	68	3.60	0.99	2.61	3.00	5.0	0.25	Soil unusually dry and hard; moisture content about 7 per cent; a few cracks in surface within plat when run 34 was begun.
	35	10–21	1–03	0.96	3.60	0.72	2.88	80	3.73	0.70	3.03	3.69	1.5	0.09	
	36	10–21	0–12	0.93	3.60	0.48	3.12	87	3.89	0.47	3.42	3.79	1.0	0.06	
	34–36	......	......	4.6 †	12.00	2.76	9.24	77	......	......	......	......	......	......	

*From end of preceding run to beginning of present run **Sprinkling continuous during all runs.
†Total time from beginning of first run to end of last run.

Table 18.—Summary of Rainfall, Retention, and Runoff during Sprinkling Experiments made in 1920

Experiment Number	Plat	Date	Total† Time in Hours	Total Sprinkling Time in Hours	Total Quantities			Ratio of Runoff to Rainfall in per cent	Ratio of Retention for Last Run in Inches per Hour
					Rainfall in Inches	Retention in Inches	Runoff in Inches		
	MORAINE PARK PLATS								
1	Level Bare Soil	June 1–3	46.7	4.50	8.70	4.26	4.44	51	0.18
2	Level Sod	June 3	2.0	1.09	11.66	10.37	1.29	11	13.0
3	Level Bare Soil	July 22–23	30.7	7.58	14.80	2.50	12.30	83	0.09
4	Sloping Bare Soil	July 28–29	29.9	8.25	16.80	4.73	12.07	72	0.23
	TAYLORSVILLE PLATS								
5	Plat 1	Aug. 9–10	29.9	7.84	14.80	4.15	10.65	72	0.26
6	Plat 2	Aug. 11–12	30.8	7.81	17.83	9.88	7.95	45	0.35
7	Plat 3	Aug. 16–17	30.4	7.56	15.80	2.10	13.70	87	0.17
8	Plat 4	Aug. 18–19	30.6	7.22	15.40	2.79	12.61	82	0.20
9	Plat 1	Oct. 19	5.7	3.55	12.00	3.35	8.65	72	0.47
10	Plat 4	Oct. 21	4.6	3.22	12.00	2.76	9.24	77	0.47
11	Plat 3	Oct. 22	5.2	3.91	6.00	2.94	3.06	51	0.54

†Total time from beginning of first run to end of last run.

Table 19.—Intensity and Duration of Precipitation Before Runoff Begins

Run Number	Location	Date	Before Runoff Began: Average Rate of Sprinkling in Inches per Hour	Time in Minutes	Total Precipitation in Inches	Surface and Soil Conditions
1	Moraine Park	June 1	3.65	2.5	0.15	Same as level bare soil plat, dry.
2	Taylorsville	Oct. 23	2.80	6.0	0.28	Same as plats 3 and 4, very dry.
3	Taylorsville	Oct. 23	2.20	10.0	0.37	Same as plats 3 and 4, very dry.
4	Taylorsville	Oct. 23	0.86	42.0	0.60	Same as plats 3 and 4, except a little more vegetation.
5	Taylorsville	Oct. 23	3.69	2.8	0.17	Made in plat 4, ground wet.
6	Taylorsville	Oct. 23	3.53	2.2	0.13	Made in plat 3, ground wet.

rainfall, retention, and runoff, in inches, the ratio of total runoff to total rainfall in per cent, and the rate of retention during the last run in inches per hour, are given for each experiment, experiments being arranged chronologically and numbered consecutively.

In table 19 the average rate of sprinkling in inches per hour, the time in minutes, and the total precipitation in inches, before runoff began, are given for the special runs made in order to study the conditions causing runoff to begin. Run numbers, dates, locations, and surface conditions are also noted.

Figures 13 to 21, inclusive, show graphically the data obtained in the various experiments. Figures 13 to 15 show the results obtained on the bare soil plats at Moraine Park, and figures 16 to 21 show those obtained on the Taylorsville plats. The data secured on the sod plat at Moraine Park is so unusual, as will be explained later, that it has not been platted. The rainfall, retention, and runoff are shown by means of mass curves, separate curves being drawn for each day's observations. The rates of rainfall, retention, and runoff are, of course, shown by the slopes of the lines. The various runs are numbered, as in tables 16 and 17. Intervals between runs made on the same day are indicated by the horizontal portions of the curves. The comparatively steep parts of the retention curves at the beginnings of the runs, and also the small peaks or humps near the ends of the runs, are due to surface storage.

RAINFALL, RETENTION, AND RUNOFF

Reference to table 18 shows that with one or two exceptions the total quantities of water applied in the various experiments were larger than any actual rainfalls on record in, or near, the Miami Valley. With the exception of experiments 1, 2, and 11, the rainfall varied from 12.00 inches in about 5 hours to 17.83 inches in about 30 hours; the total runoff, from 7.95 to 13.70 inches; and the total retention, from 2.10 to 9.88 inches. In experiment 1 the total rainfall was 8.70 inches in about 2 days. Experiment 2 was run on the level sod plat at Moraine Park where the soil conditions were unusual. In experiment 11 the rate of application was purposely kept low in order to study the retention for less intense storms.

As noted in tables 16 and 17 the soil in all instances, was comparatively dry when the experiments were started. The ground at Taylorsville was a little drier in October, when experi-

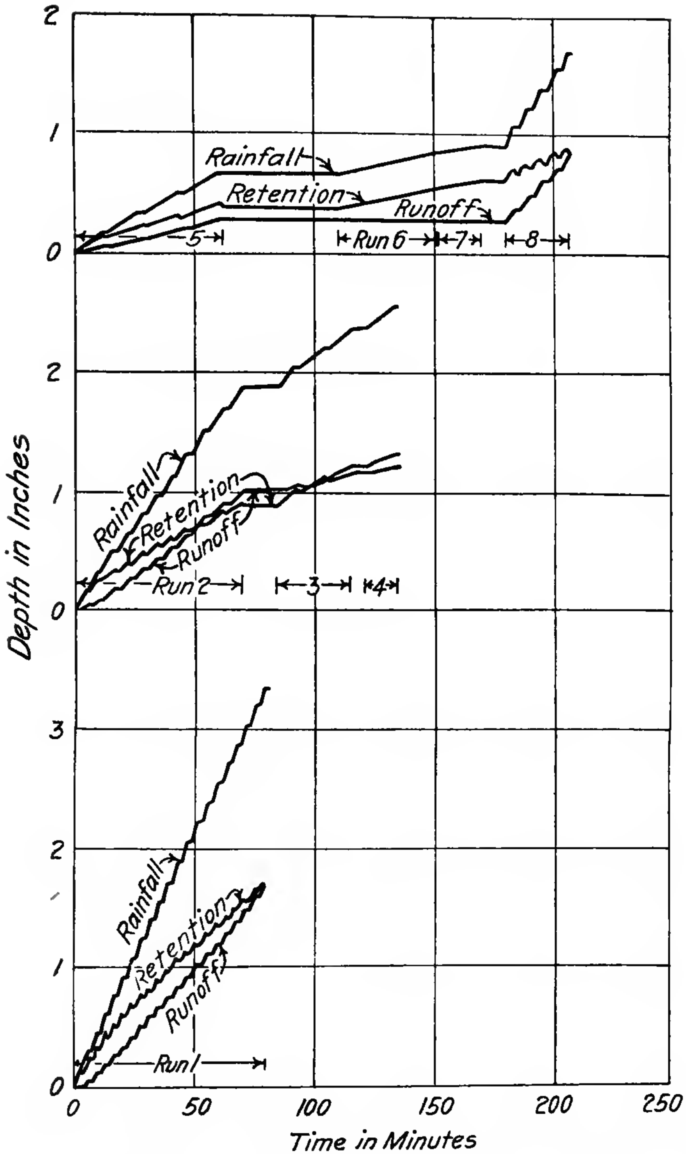

FIG. 13.—EXPERIMENT 1, MADE ON THE LEVEL BARE SOIL PLAT AT MORAINE PARK, JUNE 1 TO 3, 1920.

The curves show the total rainfall, runoff, and retention up to any instant.

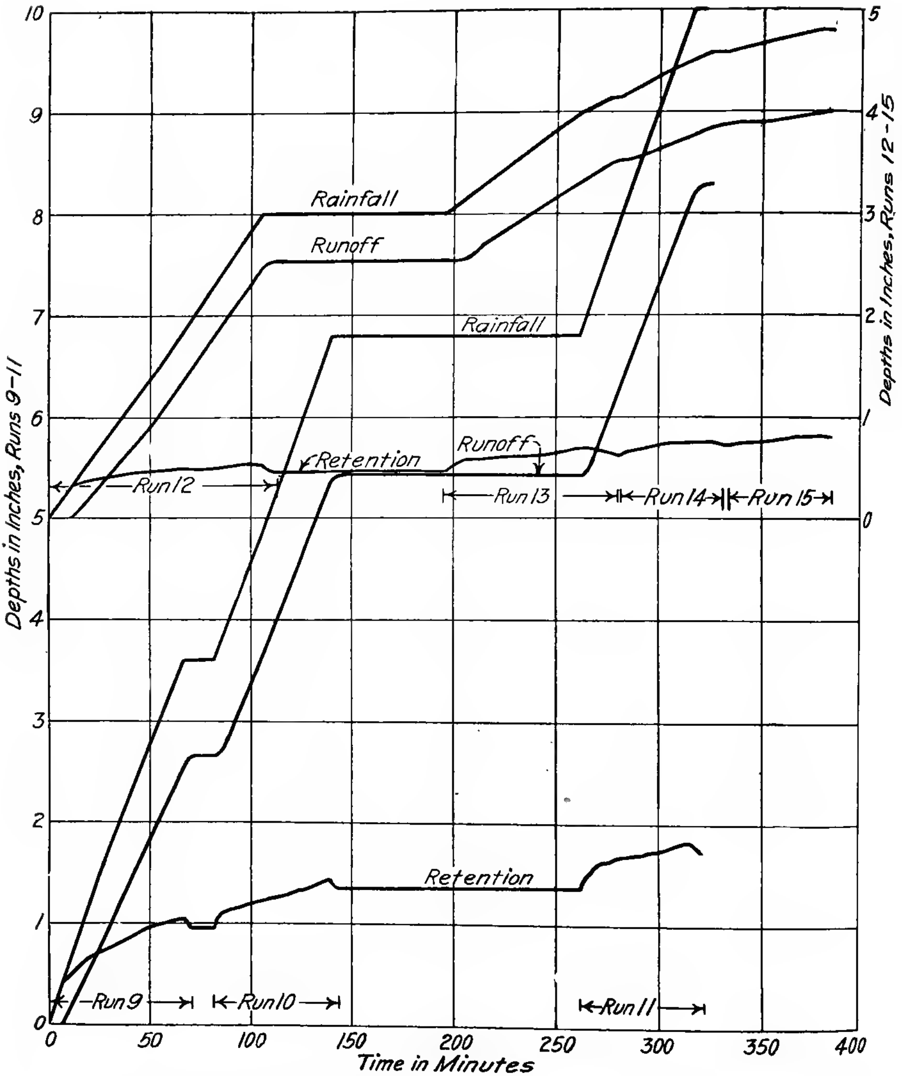

FIG. 14.—EXPERIMENT 3, MADE ON THE LEVEL BARE SOIL PLAT AT MORAINE PARK, JULY 22 TO 23, 1920.

The curves show the total rainfall, runoff, and retention up to any instant.

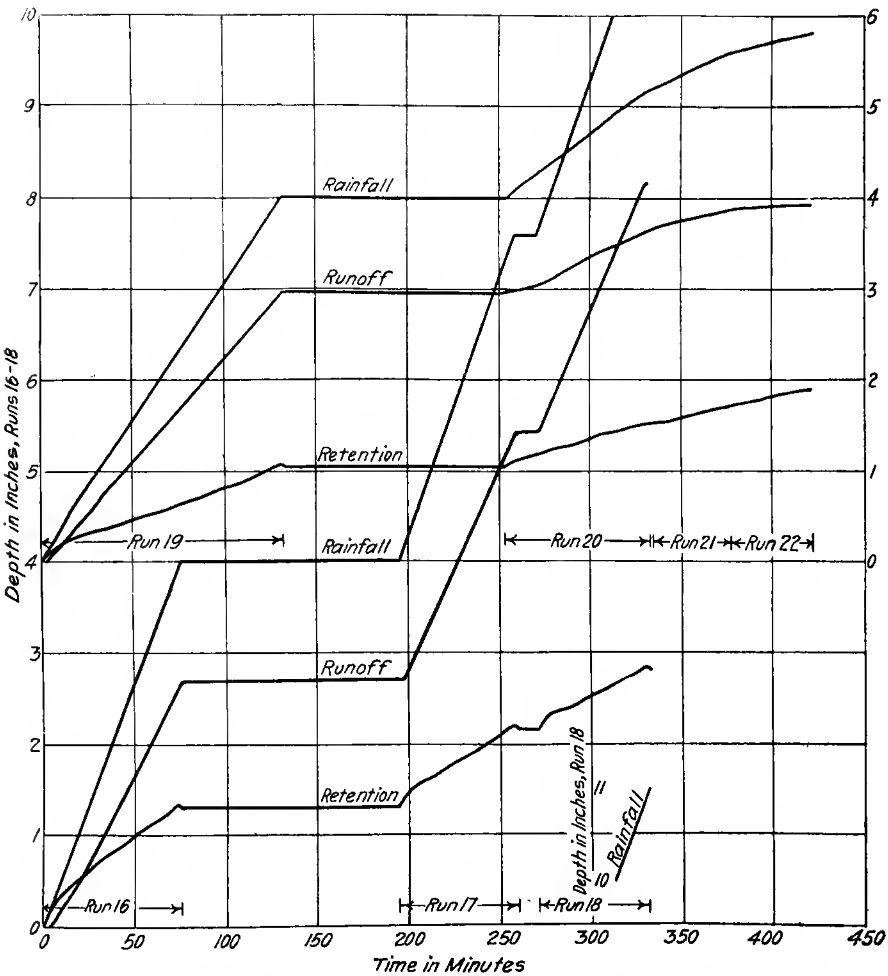

FIG. 15.—EXPERIMENT 4, MADE ON THE SLOPING BARE SOIL PLAT AT MORAINE PARK, JULY 28 TO 29, 1920.

The curves show the total rainfall, runoff, and retention up to any instant.

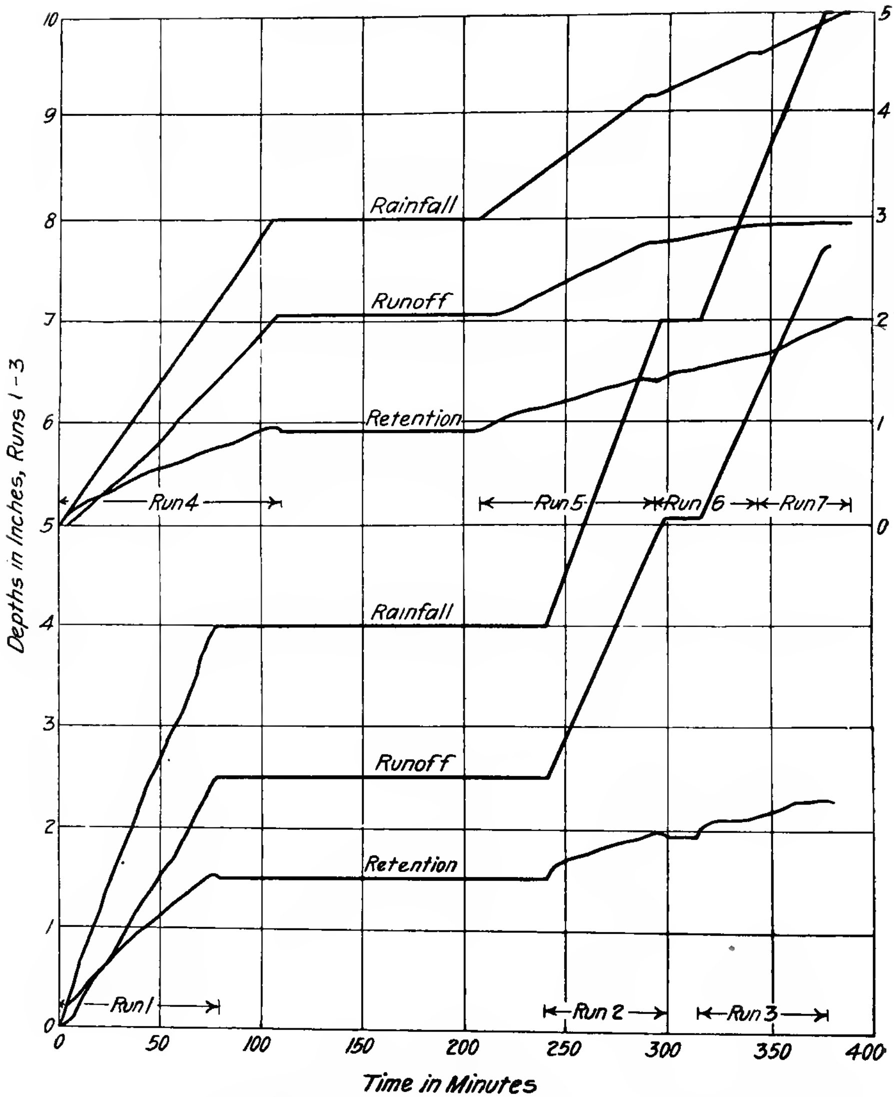

FIG. 16.—EXPERIMENT 5, MADE ON PLAT 1 AT THE TAYLORSVILLE DAM, AUGUST 9 TO 10, 1920.

The curves show the total rainfall, runoff, and retention up to any instant.

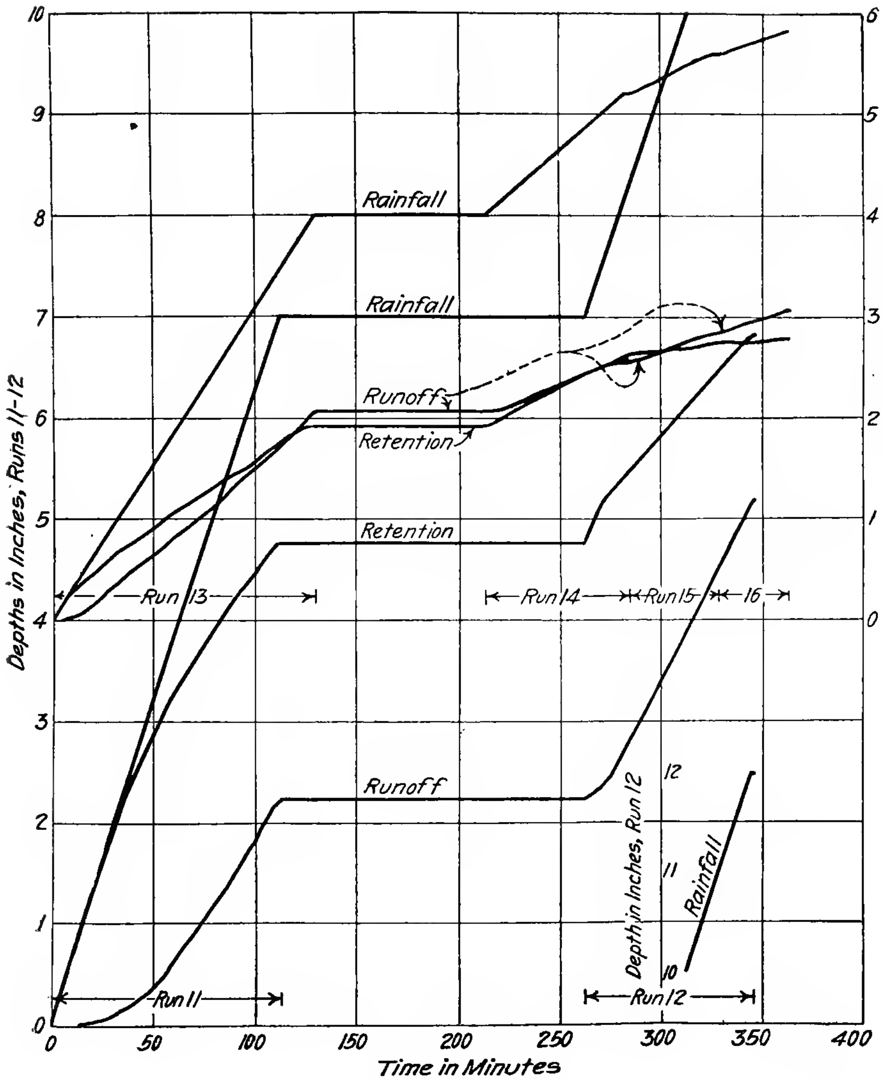

FIG. 17.—EXPERIMENT 6, MADE ON PLAT 2 AT THE TAYLORSVILLE DAM, AUGUST 11 TO 12, 1920.

The curves show the total rainfall, runoff, and retention up to any instant.

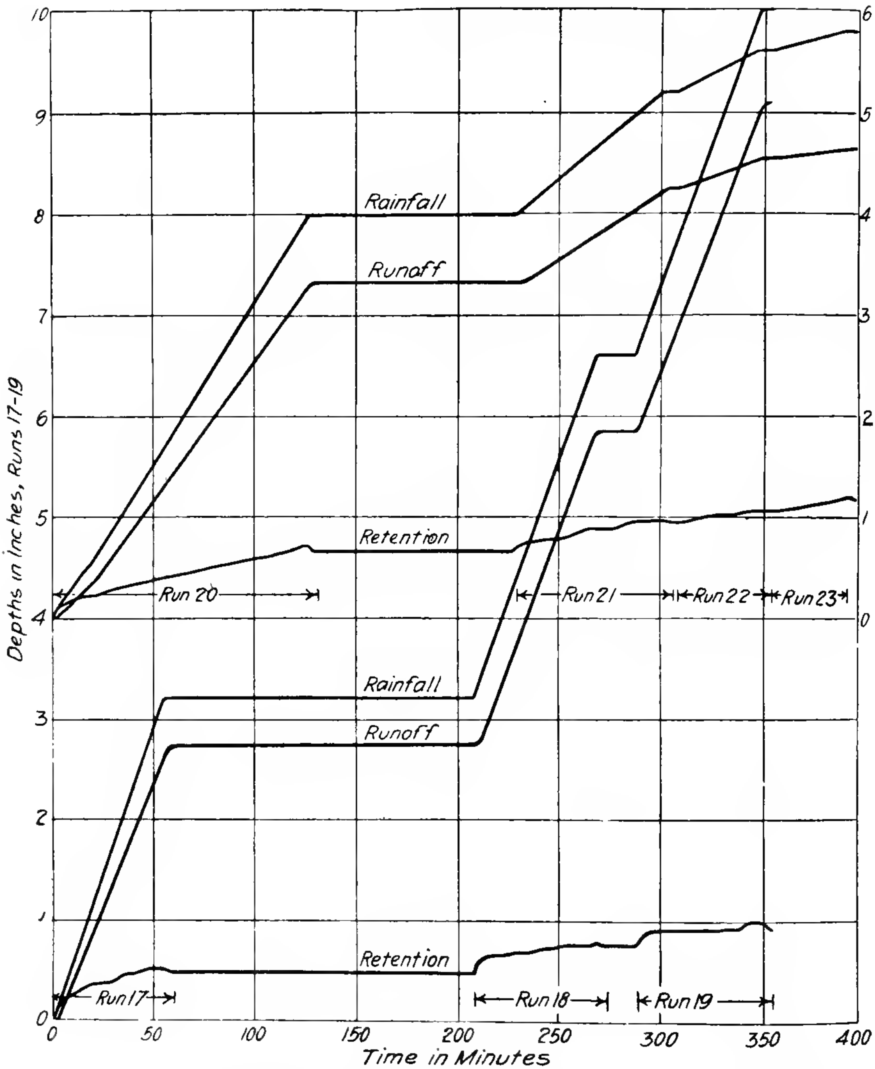

FIG. 18.—EXPERIMENT 7, MADE ON PLAT 3 AT THE TAYLORSVILLE DAM, AUGUST 16 TO 17, 1920.

The curves show the total rainfall, runoff, and retention up to any instant.

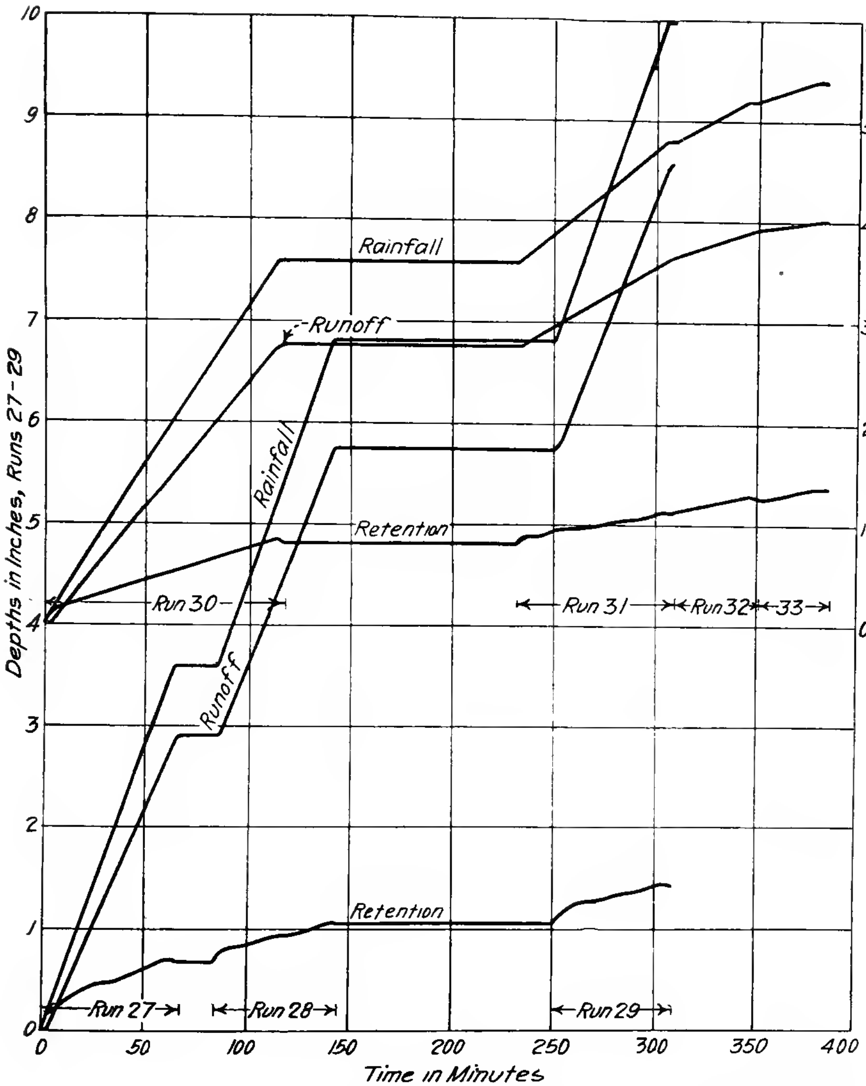

FIG. 19.—EXPERIMENT 8, MADE ON PLAT 4 AT THE TAYLORSVILLE DAM, AUGUST 18 TO 19, 1920.

The curves show the total rainfall, runoff, and retention up to any instant.

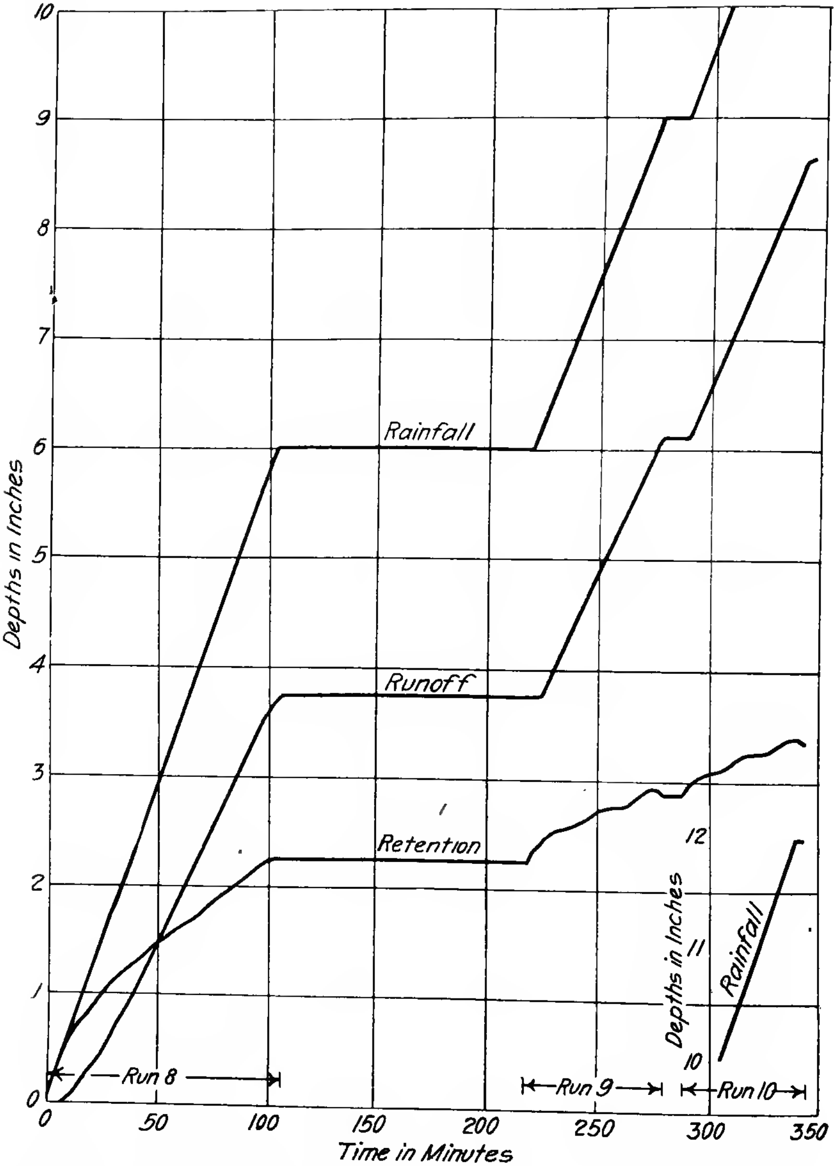

FIG. 20.—EXPERIMENT 9, MADE ON PLAT 1 AT THE TAYLORSVILLE DAM, OCTOBER 19, 1920.

The curves show the total rainfall, runoff, and retention up to any instant.

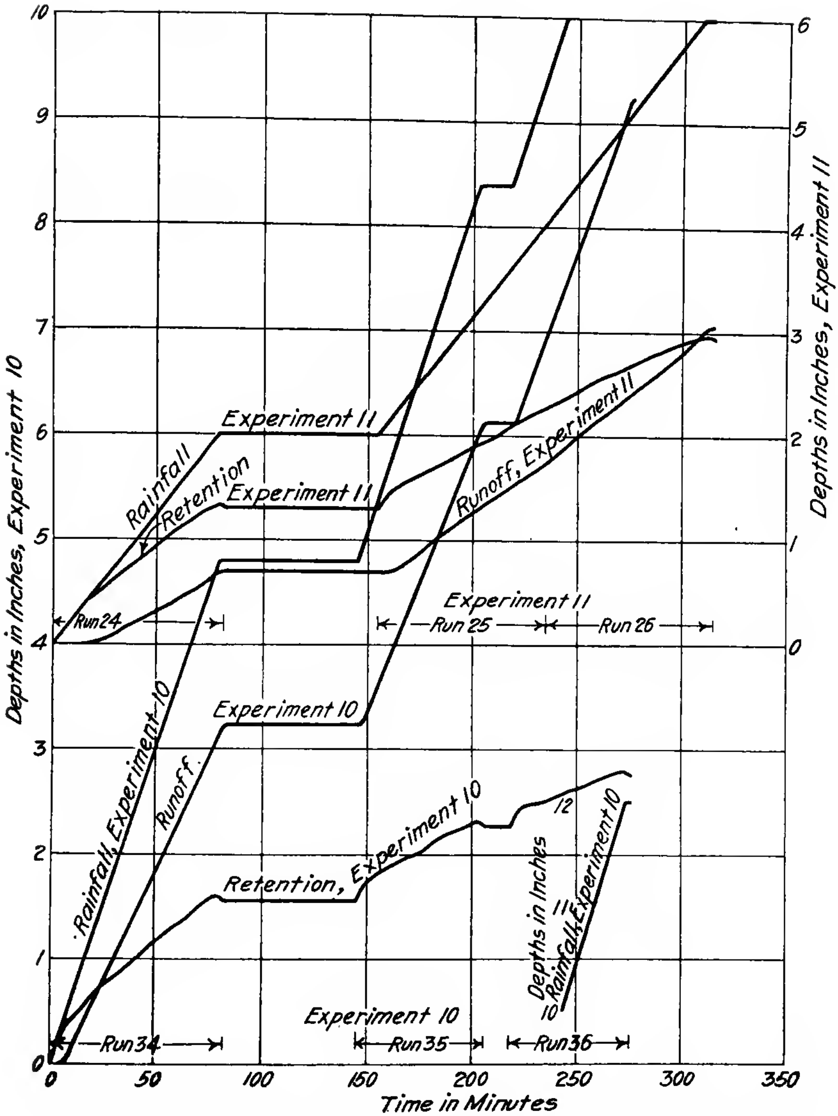

FIG. 21.—EXPERIMENTS 10 AND 11, MADE ON PLATS 4 AND 3 AT THE TAYLORSVILLE DAM, OCTOBER 21 AND 22, 1920.

The curves show the total rainfall, runoff, and retention up to any instant.

ments 9, 10, and 11 were made, than it was when the earlier experiments were begun. Consequently the data in table 18 is comparable with conditions occurring during intense summer thunderstorms, or cloudbursts, rather than to those existing during large winter storms.

It is interesting to note that although the total precipitation was unusually large in practically all of the experiments, the rates of retention when the experiments were finished were still comparatively large. This would indicate that the soil was capable of taking up considerable additional moisture. The lowest rate of retention given in table 18, 0.09 inches per hour on the level bare soil plat at Moraine Park, would correspond to a total absorption of 0.90 inches in 10 hours or 2.16 inches in 24 hours if continued for such periods of time. It should be noted that these rates of retention are lower, in most instances, than they would have been if the rates of precipitation had been higher, since it will be shown later that the rate of retention generally increases somewhat, if only slightly, as the rate of precipitation increases.

The values of retention include soil absorption, percolation, and evaporation. Since the experiments were run on comparatively warm summer days when some wind was blowing, it is possible that the evaporation may have amounted to as much as 0.05 of an inch an hour in certain instances, although it is not believed that it ever could have exceeded this appreciably. At Moraine Park, owing to the shallow surface soil, retention must have been mostly percolation after the first run of each experiment.

Moraine Park Sod

Experiment 2, made on the level sod plat at Moraine Park, shows an unusually large retention. Of the total precipitation, 11.66 inches in 1.09 hours, only 1.29 inches ran off, leaving a retention of 10.37 inches. By referring to table 16 it will be seen that a rate of precipitation of 4.17 inches per hour was applied for 30 minutes with no runoff whatever; that a rate of 14.4 inches per hour was then applied for 12.2 minutes before runoff began; that this rate was continued for about 13 minutes, obtaining an average rate of runoff of only 0.4 inches per hour; and that a rate of 20.4 inches per hour was then applied for about 10 minutes, causing a rate of runoff of only 7.4 inches per hour, or less than half of the rate of application. In the last run the

water was applied with a garden hose, the rate being determined by tank measurements immediately before and after the run. In the first two runs the sprinkling was somewhat intermittent, since only one sprinkling can was available. The times given above are the net sprinkling times, not including the intervals during which the can was being filled.

These extremely unusual results are due to the unusual soil conditions existing at this plat. As explained in chapter III the soil is loose and is filled with roots down to the depth where the material is mostly sand and gravel. Consequently the water can percolate downward at very great rates.

The data obtained by sprinkling agrees with the natural rainfall and runoff records given in the preceding chapter. It was there shown that runoff on this plat occurred very infrequently; and that when it did occur it was generally due to melting snow or to rain at times when the ground surface was frozen.

Moraine Park Bare Soil

Experiments 1, 3, and 4 were made on the bare soil plats at Moraine Park, numbers 1 and 3 being made on the level plat and number 4 on the sloping plat. The soil in the sloping plat when experiment 4 was begun was in about the same condition as the soil in the level plat when experiment 1 was started. It was comparatively dry and loose in both cases. When experiment 3 was started, however, the soil in plat 1, although dry, was hard and packed, and consequently in a much more impervious condition. This was caused by the trampling of a herd of cattle which was turned into the field in which the plats are located, immediately after experiment 1 was made, while the soil was still in a saturated condition. The sprinkling was intermittent during experiment 1 due to only one can being available, but was continuous during experiments 3 and 4.

By referring to table 18 it will be seen that the total retention during experiment 1 was considerably greater than the total during experiment 3, although the quantity of water applied in the latter instance was about 70 per cent greater than in the former. This, of course, would be expected due to the difference in soil conditions and in sprinkling methods. For experiment 4 the retention was 4.73 inches or only slightly more than for experiment 1, although the total precipitation was practically twice as great. The relatively smaller retention during ex-

periment 4 was due to the slope of the ground as well as to the difference in sprinkling methods.

The total runoff was 4.44 inches, or about 51 per cent of the total rainfall, during experiment 1; 12.30 inches, or about 83 per cent of the total rainfall, during experiment 3; and 12.07 inches, or about 72 per cent of the rainfall, during experiment 4.

Taylorsville Plats

Experiments 5 to 11, inclusive, were run on the plats at Taylorsville; numbers 5 and 9 on plat 1, number 6 on plat 2, numbers 7 and 11 on plat 3, and numbers 8 and 10 on plat 4. Plat 2 was spaded and raked before experiment 6 was begun, as previously noted. The other plats were in their natural condition. Sprinkling was continuous during all experiments.

Experiments 5 to 8, inclusive, were practically the same as regards time of sprinkling and total quantity of water applied, except that the total precipitation during number 6 was from 2 to 3 inches greater than during the others. Experiments 9 and 10 were similar, each being run in about the same time and at about the same rainfall intensity. Experiment 11 was run in about the same time as numbers 9 and 10 but the water was applied at a less intense rate.

Reference to experiments 5 to 8, inclusive, in table 18 shows that the retention on plat 2, in experiment 6, where the soil had been loosened, was more than twice as great as on plat 1, in experiment 5, where the soil was similar in composition and texture but had not been spaded; and about four times as great as on plats 3 and 4, experiments 7 and 8, where the soil was mostly clay and had not been loosened. The total retention on plat 2 was 9.88 inches or about 55 per cent of the rainfall; as against 4.15 inches or about 28 per cent of the rainfall, on plat 1, and about 2.45 inches or about 16 per cent of the rainfall, on plats 3 and 4. The total runoff amounted to 7.95 inches or about 45 per cent of the rainfall in experiment 6; to 10.65 inches or about 72 per cent of the rainfall in experiment 5; and to about 13.15 inches or about 84 per cent of the rainfall in experiments 7 and 8.

In experiment 9, made on plat 1 in October when the soil was slightly drier than in August, the retention amounted to 3.35 inches, or about 28 per cent of the precipitation. During runs 1 to 3 of experiment 5, which are comparable with experiment 9, the retention amounted to 2.30 inches or about 23 per cent of the rainfall. Experiments 10 and 11 also show greater values

of retention than were obtained in the parts of experiments 8 and 7 which are comparable. It is interesting to note that the retention during experiment 11 was slightly greater than during experiment 10 although the total precipitation in the latter was twice as great. This is due to the slightly greater sprinkling time during experiment 11. The rate of retention for plats 3 and 4 varies only slightly with the rate of rainfall, as will be shown later. Conditions during experiments 10 and 11 are shown in figure 21.

RAINFALL AND RUNOFF RATES ON SATURATED SOILS

The data in tables 16 and 17 is essentially data on rainfall, retention, and runoff on saturated soils. Although the soil was comparatively dry when the experiments were started in all cases, it soon became saturated to such a depth that runoff began. By the end of the first run the soil was generally saturated to such a depth that the rate of runoff caused by a given rate of precipitation was practically constant. This was true for all experiments except number 2, made on the sod plat at Moraine Park, where the soil conditions were unusual, as previously mentioned; and numbers 10 and 11, made on the hill plats at Taylorsville, in October, when the soil was somewhat drier than in the earlier experiments. At Taylorsville, the actual depths of saturation probably varied somewhat during the later runs of the other experiments, increasing as the work progressed. However, these variations may, for the present, be neglected. At Moraine Park the sand and gravel deposits, underlying the 2-foot layer of surface soil, afforded ready drainage and thus prevented the extension of saturated conditions below this depth.

Moraine Park Bare Soil

The rates of rainfall, retention, and runoff for the bare soil plats at Moraine Park, given in table 16, are shown graphically in figure 22, rates of rainfall being platted as ordinates against rates of runoff as abscissas. The rates of retention are represented by the horizontal or vertical distances from the platted points to the 45° line, curve D, drawn through the origin. This 45° line represents the limiting conditions of runoff. A point would fall on this line only when the runoff rate was equal to the rainfall rate. Points representing runs where the soil was not

saturated have been identified by placing near them the run numbers. Other points have not been numbered.

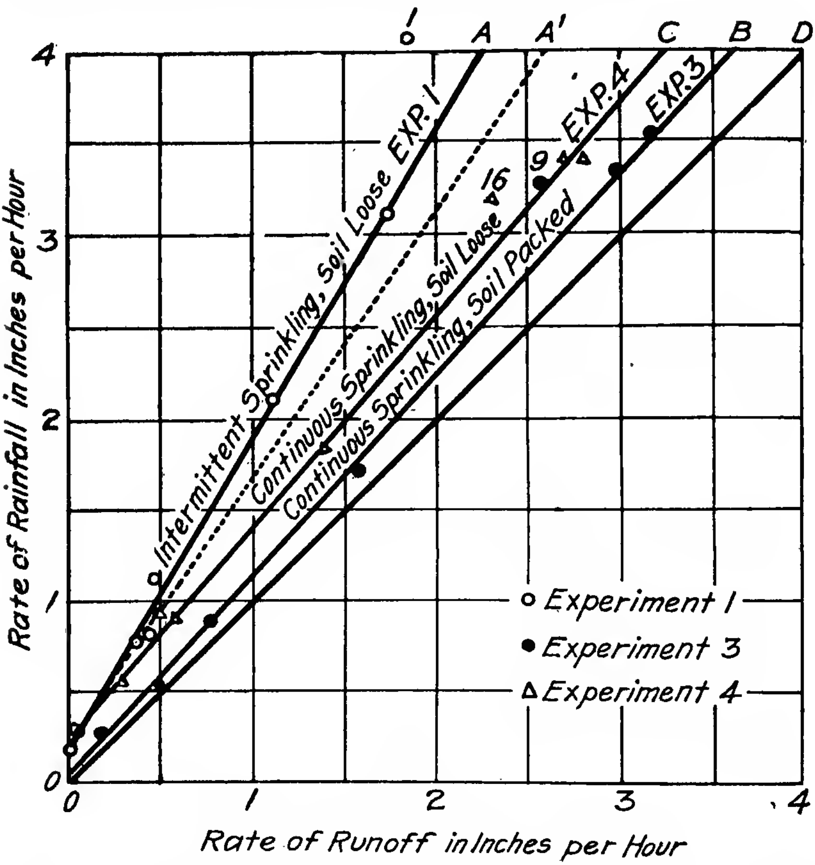

FIG. 22.—RATES OF RAINFALL AND RUNOFF ON BARE SOIL PLATS AT MORAINE PARK.

Runs in which the soil was not saturated are numbered. Experiments 1 and 3 were made on the level plat and experiment 4 on the sloping plat. Curve D is a 45 degree line.

For each experiment a line has been drawn so as to balance all points except those where the soil was not saturated. Consequently these lines show the variations in the rate of runoff caused by variations in the rate of rainfall, during the summer and fall, after the soil has become saturated by a fairly heavy and intense precipitation.

Variations in the rate of retention due to variations in the rate of rainfall are shown by the differences between the lines

representing the observations and the 45° line. Differences in the relation between rainfall and runoff for saturated soils due to variations in soil texture and in surface conditions are shown by the differences in the slope and in the location of curves A, B, and C.

Curve A averages the various runs of experiment 1, made on the level plat, curve B averages those of experiment 3, also made on the level plat, and curve C averages those of experiment 4, made on the sloping plat. It will be noticed that the rates of runoff corresponding to given rates of rainfall were considerably lower in experiment 1 than they were in experiment 3, due to the different method of sprinkling as well as to the different condition of the soil; also that they were considerably lower in experiment 1 than they were in experiment 4, due to the different method of sprinkling and to the different slopes of the surfaces.

In all three curves the rate of retention increases as the rate of rainfall increases. In curves B and C this is due entirely to the head caused by the greater depth of water on the ground, this increased head producing an appreciable effect because of the comparatively shallow depth of the surface soil. While the effect of varying head must have been fully as great in curve A as in curves B and C, the method of sprinkling and of calculating the rates of runoff also had some effect. If the sprinkling had been continuous in experiment 1, or if it had been possible to eliminate surface storage effects in calculating the rates of runoff, curve A would probably have fallen in some position intermediate between its present position and that of curve B, as at A′.

Probably the most interesting thing brought out by figure 22 is that the relation between rates of rainfall and runoff may be represented by straight lines; that is, that the relation represented by any one of these lines may be expressed by the straight line equation

$$y = sx + b$$

where y is the rate of rainfall, x is the rate of runoff, b is the intercept on the y axis, and s is the slope of the line.

It will be noticed that the value of b is about 0.20 inches per hour for curve A, 0.05 for curve B, and 0.24 for curve C. These are the rates of precipitation that can be maintained indefinitely on the Moraine Park bare soil plats, during the summer and fall when the soil is saturated, without any runoff whatever occur-

ing; that is, for these rates or lower rates, the water can percolate downward as fast as the rain falls.

Since the rate of percolation decreases with a decreasing temperature the value of b may be slightly smaller during the winter and spring. Allen Hazen,* speaking of friction losses in sand and gravel, says "I have found that the friction also varies with the temperature, being twice as great at the freezing point as at summer heat, both for coarse and fine sands." It is possible however, that in a shallow surface soil as at Moraine Park the loosening due to freezing and thawing may counteract to a certain extent the effect of the decrease in temperature.

Since curves A and C represent soil conditions comparable with those existing when the natural rainfall and runoff data was collected, the values of b determined from the sprinkling experiments furnish a satisfactory check on the conclusion reached in the preceding chapter; namely, that water can percolate through the surface soil on the bare soil plats, when the ground is saturated, at a rate as great as 0.25 of an inch an hour.

Taylorsville Plats

Figure 23 shows the Taylorsville data, contained in table 17, platted in the same manner as in figure 22. Curve D is the 45° line as before. Curve E averages the data taken on plat 1, curve F averages that taken on plat 2, and curve G averages that taken on plats 3 and 4. The conditions on plats 3 and 4 are practically identical, so that it is not necessary to draw a line for each plat. In platting the points, however, different symbols were used for the two plats, so that the agreement of the data may be seen. Sprinkling was continuous during all runs.

The increased slope of curve F over that of curve E shows the increased retention obtained by spading, or loosening, the soil. It will be noticed that the rate of retention increases considerably as the rate of precipitation increases, in the case of plat 2; but that it is practically constant in the case of plat 1. The slightly higher rates of runoff shown by curve G over those shown by curve E are due to the slightly greater impermeability of the clay soil at the hill plats. The rate of retention at the hill plats is similar to that at plat 1, in that it increases only

*Some Physical Properties of Sands and Gravels, by Allen Hazen, Massachusetts State Board of Health, Boston, Massachusetts, Twenty-fourth Annual Report, page 553, 1892.

slightly with the increasing rate of precipitation. It is comparatively small throughout the range covered by the data.

Here, also, the relations between rates of rainfall and runoff for saturated soil may be shown by straight lines. The value of b is seen to be 0.30 inches per hour for curves E and F and about 0.20 inches per hour for curve G, meaning that precipitation can

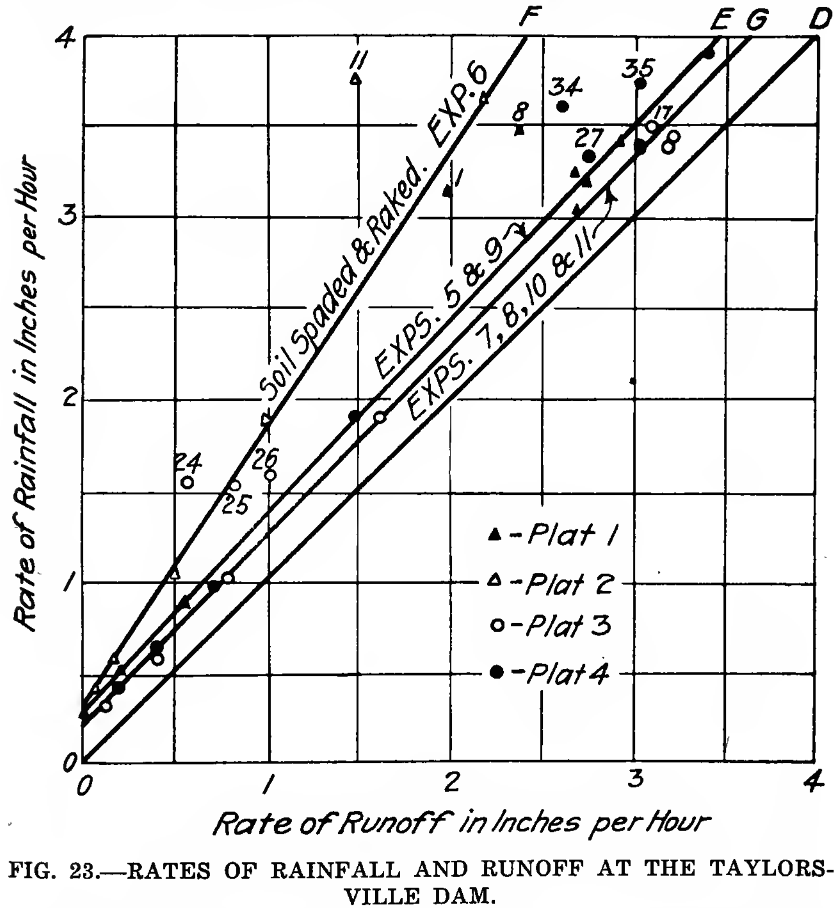

FIG. 23.—RATES OF RAINFALL AND RUNOFF AT THE TAYLORSVILLE DAM.

Runs in which the soil was not saturated are numbered. Note the increased retention obtained by spading the soil. Curve D is a 45 degree line.

occur at these rates, during the summer and fall when the surface soil is saturated, without any runoff taking place. It should be noted that these values are practically the same as those obtained at Moraine Park notwithstanding the difference in subsoil. For winter and spring conditions, however, the values of

b at Taylorsville may be lower than at Moraine Park, due to the greater depth of saturation and the lack of adequate soil drainage.

Average Relations

In figure 24 the various curves of figures 22 and 23 have been brought together. Points have not been shown since they would

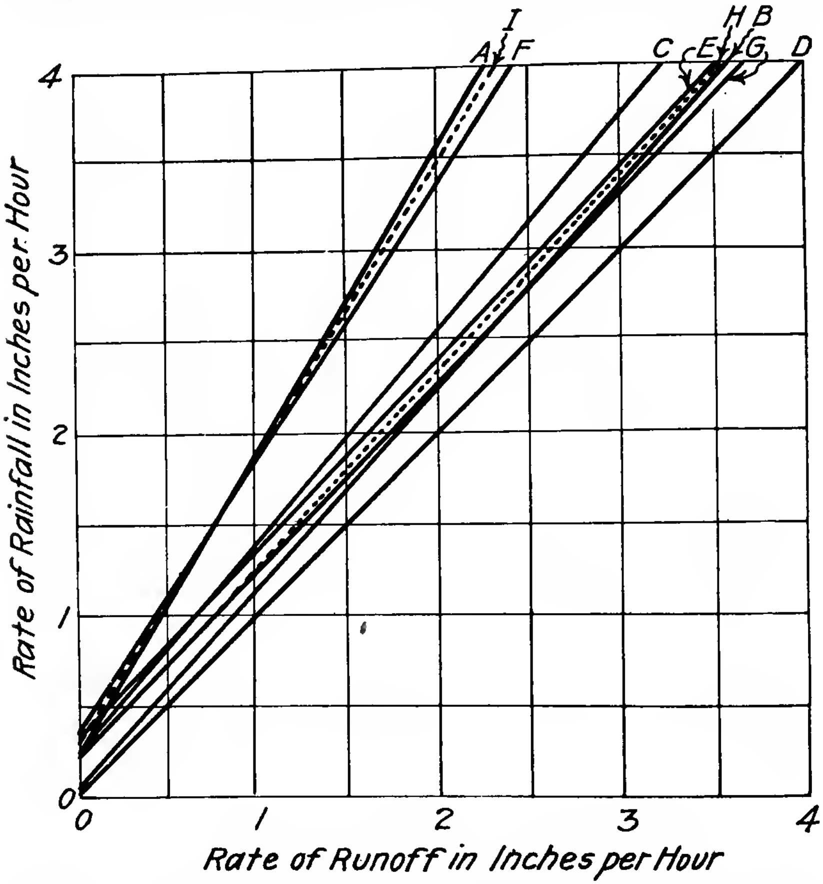

FIG. 24.—AVERAGE RELATIONS BETWEEN RATES OF RAINFALL AND RUNOFF, SOIL SATURATED.

The two dotted lines represent the average relations shown by the two groups of full lines. For identification of full lines see figures 22 and 23.

only confuse the diagrams. It will be noticed that the lines fall into two separate groups; first, curves A and F, and, second, curves B, C, E, and G. Curve H has been added to represent the

average relation between rainfall and runoff rates shown by the lines of the second group, and curve I has similarly been drawn to represent the average relation shown by those of the first group.

The relation shown by curve H may be expressed by the formula

$$y = 1.07x + 0.20 \tag{1}$$

where y is the rate of rainfall and x the rate of runoff, both expressed in inches per hour. Since y is the cause and x the effect it seems more advantageous to change equation 1 to the form

$$x = 0.93\ (y - 0.20) \tag{2}$$

It will be noticed that the coefficient of the quantity $(y - 0.20)$ is not greatly different from unity; or in other words that curve H is nearly parallel to curve D. This means that the rate of retention increases only slowly with an increasing rate of precipitation. For practical purposes this variation in the rate of retention may be neglected. Taking the value of the retention as 0.30 inches per hour, a value corresponding to a rate of precipitation of 1.50 inches per hour by curve H, the relation between rates of rainfall and runoff may be expressed by the equation

$$x = y - 0.30 \tag{3}$$

The line representing equation 3 would be parallel to curve D and a constant distance above, equivalent to 0.30 inches per hour.

Consequently, during the summer and fall when the ground is saturated, rates of runoff from soils similar to those represented by curves B, C, E, and G may be estimated by simply deducting 0.30 inches per hour from the rates of rainfall.

Curve I, representing the average relation for curves A and F, may be expressed by the equation

$$y = 1.60x + 0.25 \tag{4}$$

or, solving for x,

$$x = 0.62\ (y - 0.25) \tag{5}$$

The retention would then be expressed by the equation

$$y - x = 0.60x + 0.25 \tag{6}$$

This time the rate of retention increases appreciably as the rate of rainfall increases; and, consequently, it will not be advisable to replace the slope coefficient 1.60 by unity.

Equations 3, 5, and 6 are applicable during the summer and fall; on areas similar to those where the experiments were made, after the surface soil has become saturated by a precipitation of three or four inches falling in one of two days. The data

given in the preceding chapter indicates that equation 3 is applicable on the sloping bare soil at Moraine Park during the winter and spring after a half an inch or an inch has fallen, although it probably will give rates of runoff slightly too low at such times. The rates of percolation during the winter and spring on plats 1, 3, and 4 at Taylorsville, after an inch has fallen, may differ somewhat from the 0.30 of an inch an hour shown by equation 3, no data being available for these plats for such seasons of the year. The rate of percolation on plat 2 probably decreases as the soil becomes packed by the winter and spring rains.

The average relation between rates of rainfall and runoff for the Miami Valley during the summer and fall when the surface soil is saturated, probably lies somewhere between those shown by equations 3 and 5. It is, of course, very difficult to estimate the average soil conditions over a large drainage area. However, considering that practically throughout the valley the amount of vegetation exceeds that on plats 1, 3, and 4 at Taylorsville, and also that the greater part of the land is cultivated, it seems fairly certain that the average rate of retention would exceed that used in determining equation 3. It does not seem possible though, that the retention could amount to as much as that obtained on plat 2 at Taylorsville, where the soil had been thoroughly spaded and raked just before the experiment was made.

RAINFALL AND RUNOFF RATES, SOIL NOT SATURATED

When the ground is not saturated the relation between rates of rainfall and runoff varies greatly with the amount of moisture in the soil, as well as with the soil texture and the surface conditions. On a given plat the drier the soil the greater will be the rate of retention and the smaller will be the rate of runoff corresponding to a given rate of rainfall.

Experiments 10 and 11, made on plats 4 and 3 at Taylorsville, furnish data on the relation between rates of rainfall and runoff for different amounts of soil moisture. Since the soil and surface conditions are the same at these two plats, and since the amount of moisture present when experiments 10 and 11 were started was the same, it is possible to select portions of these experiments in which the amount of soil moisture present was the same for both plats. The rates of rainfall and runoff can then be calculated for these portions for both experiments and

the difference in the runoff rate for a given portion will be due entirely to the difference in the rainfall rate. The rates may then be platted as in figures 22 and 23 and curves may be drawn to represent the relations for the different amounts of soil moisture.

In figure 25 the circles show the rainfall and runoff rates determined in this manner for the following ranges of retention.

From 0.00 to 0.65 inches
From 0.65 to 1.30 inches
From 1.65 to 2.30 inches
From 2.40 to 2.75 inches

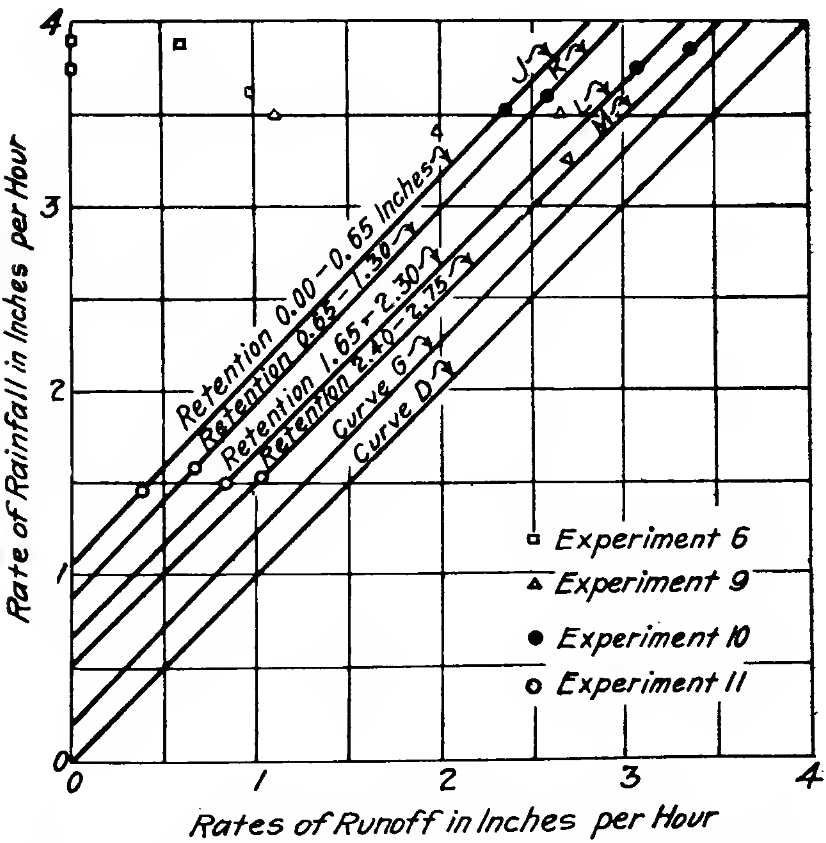

FIG. 25.—RATES OF RAINFALL AND RUNOFF AT THE TAYLORSVILLE DAM WHILE SOIL IS BECOMING SATURATED.

Lines have been drawn through points calculated from experiments 10 and 11.

The upper set of circles were determined from experiment 10 and the lower set, from experiment 11. Straight lines have been drawn through the points for each range in retention, curves J, K, L, and M; and a 45° line, curve D, has been added as in figures 22 to 24. For comparative purposes, curve G of figure 23, representing saturated surface soil conditions in plats 3 and 4, has also been added. Since only two points are available for each line, it is, of course, not known whether they should be straight or curved. They were drawn straight because it has been shown that for saturated soil conditions the curves are straight.

It will be noticed that curves J, K, L, and M are spaced rather uniformly, and that they are nearly parallel to curve D, the 45° line. However, if the experiments had been carried further, it is likely that the succeeding lines would have been increasingly closer together as they approached curve G, since curve G was based primarily on experiments in which the total sprinkling time, as well as the amount of moisture in the soil when the observations were started, was greater than in experiments 10 and 11.

Curves J, K, L, and M illustrate, for plats 3 and 4, the variations in runoff and retention rates caused by variations in rainfall rates and in total retention. Retention rates are shown by the horizontal or vertical distances from the various lines to curve D. The variations in runoff and retention rates due to variations in soil texture may be indicated by showing, on figure 25, points calculated for plat 1 for similar ranges in retention during experiment 9. The soil in plat 1 when experiment 9 was begun contained about the same quantity of moisture as the soil in plats 3 and 4 when experiments 10 and 11 were started. Points calculated for experiment 9 are shown by the triangles in figure 25.

It will be noticed that the triangle corresponding to a range in retention from 0.00 to 0.65 inches falls a considerable distance to the left of curve J, thus indicating a considerably greater rate of retention and a correspondingly smaller rate of runoff for plat 1. The succeeding points, however, fall increasingly closer to the curves for plats 3 and 4. The last point, corresponding to a retention from 2.40 to 2.75 inches, is very close to curve M. This means that at Taylorsville the runoff from the clay soils on the hills is appreciably greater than the runoff from the loam

in the valley, when the soil is dry, but not materially different when the soil is saturated.

The effect of cultivation on retention and runoff may be shown on figure 25 by platting points computed from experiment 6, made on plat 2 at Taylorsville. As previously noted the soil in this plat was spaded and raked before the experiment was started. Points computed for the ranges in retention used in determining curves J, K, L, and M, are shown by the squares in the upper part of the diagram. It will be noticed that the points corresponding to ranges from 0.00 to 0.65 inches and from 0.65 to 1.30 inches, show no runoff whatever. Although the curves in figure 17 show the runoff as beginning when the retention had amounted to about an inch, the average rate before the retention reached 1.30 inches was so small that it could not be shown in figure 25. The points corresponding to ranges in retention from 1.65 to 2.30 and from 2.40 to 2.75 inches both fall to the left of the point calculated from experiment 9, plat 1, for the range from 0.00 to 0.65 inches. This illustrates the relatively great amount of retention obtained by cultivation. Reference to figure 17 shows that after runoff did begin on plat 2, the rate increased gradually throughout the first run. That the increase was gradual rather than abrupt was due to the presence of air in the soil.

The ranges in retention for which the points were computed are noted on the curves in figure 25. Points corresponding to similar ranges during other experiments, or during actual rainfalls, will fall on these lines only when the soil conditions, as regards texture, temperature, and moisture, at the beginning of the precipitation are the same as they were in experiments 10 and 11. Consequently, in order to use curves J, K, L, and M in calculating runoff from rainfall, it will be necessary to estimate the condition of the soil when the rainfall begins. This estimate can probably be made closely enough that the runoff rate will be determined with a fair degree of accuracy. For instance, if it is estimated that when a rainfall of 2 inches per hour, lasting an hour, began, the condition of the soil was the same as in experiments 10 and 11, the runoff rate of about an inch an hour, shown by the curves in figure 25, is probably accurate within 25 per cent or within a quarter of an inch an hour. This uncertainty would decrease in amount as the soil became saturated. While an uncertainty as great as 25 per cent is un-

desirable, it is doubtful if an estimate based on judgment alone would be as accurate as one based on the curves of figure 25.

The data secured at Moraine Park is hardly sufficient to warrant the preparation of a diagram such as figure 25. However, the differences in retention and runoff due to variations in soil texture and surface slope may be studied in figures 13, 14, and 15, illustrating experiments 1, 3, and 4. Experiment 1 was made on the level bare soil plat in June, experiment 3 on the same plat in July, after the soil had been trampled and packed by cattle, and experiment 4 on the sloping bare soil plat when the soil was comparatively loose. Considering the first run of each experiment the retention rates are seen to have been considerably greater, and the runoff rates considerably less, during experiment 1 than during experiments 3 and 4. During experiment 4 the retention rates were slightly greater, and the runoff rates slightly less, than during experiment 3. This means that the increase in runoff due to the trampling and packing of the soil was slightly greater than that due to the increase in the slope of the surface.

The average rate of retention of 0.90 inches per hour obtained on the sloping plat in run 16, for a period of an hour and 15 minutes, checks the conclusion reached in the preceding chapter that water can be absorbed by the bare soil at times during the summer when the soil is unusually dry, at a rate as great as 1.00 inch per hour for intervals as long as 30 minutes.

CONDITIONS BEFORE RUNOFF BEGINS

A knowledge of the conditions necessary before runoff begins is valuable in studying rainfall and runoff. During many showers of comparatively short duration no runoff takes place although the intensity of the precipitation may be relatively great. During other showers of longer duration and lesser intensity similar conditions exist as regards runoff. In order for runoff to begin it will be necessary for two conditions to be fulfilled. First, the precipitation must occur at a rate greater than the rate at which it can be absorbed by the soil; and, second, the excess rate must continue long enough to fill the surface storage available by reason of the small depressions in the surface, accumulations of dead grass or leaves, growing vegetation, and other factors. The relative importance of these two conditions, of course, varies with the soil and surface characteristics. If the soil is bare and free from depressions, rates of precipitation and

soil absorption are predominant. If the soil is covered with a heavy sod or a deep deposit of forest litter, surface storage is the determining factor.

While it is not possible to differentiate between these two factors in a given instance, it is interesting to discuss their combined effect. Referring to run 1 of table 16 made on the level bare soil at Moraine Park when the ground was dry, it is seen that a rate of rainfall of 4.25 inches per hour caused runoff to begin in 2.0 minutes, or after a total of 0.14 inches had fallen. Run 1 of table 19, made on similar soil on the same day, showed that a rate of rainfall of 3.65 inches per hour caused runoff to begin in 2.5 minutes, or after a total of 0.15 inches had fallen. Run 16 of table 16, made on the sloping bare soil plat when the ground was dry, showed that a rate of 3.00 inches per hour resulted in runoff after 3.5 minutes, or after the total amounted to .18 inches. These results confirm the conclusion reached in the preceding chapter; namely, that water cannot be absorbed by the bare soil at Moraine Park at any time, no matter how dry it is, at a rate as great as 3.00 inches per hour for periods as long as 5 minutes. The apparent exception to this, indicated by run 9 of table 16, in which a rate of 3.65 inches did not cause runoff until 5.5 minutes, is due to the different condition of the surface, the surface in this instance containing a considerably greater number of small depressions.

Runs 1, 17, and 27 of table 17, made in August when the ground was about as dry as in the runs mentioned above, show that the soil at Taylorsville in plats 1, 3, and 4, is about the same as at Moraine Park as regards beginning of runoff. However, run 11, made on plat 2 where the soil had been spaded, shows a great difference. In this case a rate of 3.90 inches per hour did not cause a measurable quantity of runoff for 22 minutes, or until the total precipitation had amounted to 1.43 inches. The following morning, when the soil was practically saturated a rate of 1.85 inches per hour resulted in runoff in 6 minutes, or after 0.18 inches had fallen.

Runs 8, 24, and 34 of table 17, made on plats 1, 3, and 4 in October, when the soil was somewhat drier than in August, show slightly greater values of retention preceding runoff, than do runs 1, 17, and 27. Other runs of tables 16 and 17 show the conditions before runoff when the ground is practically saturated.

Figure 26 shows graphically the data discussed above. Times

in minutes required for runoff to begin are platted as abscissas against the corresponding rates of precipitation as ordinates. Points corresponding to all runs in table 19 have been platted, but only those corresponding to the first run of each day have been platted from tables 16 and 17, since runs made on the same day were frequently only a few minutes apart. Different sym-

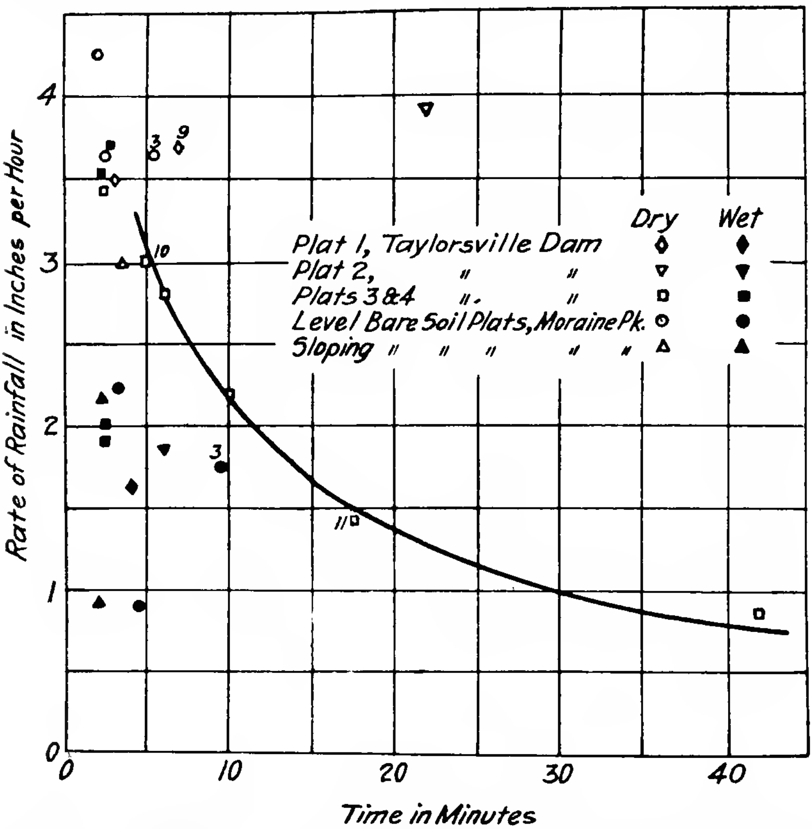

FIG. 26.—INTENSITY AND DURATION OF RAINFALL BEFORE RUN-OFF BEGINS.

Data secured at the Moraine Park and Taylorsville plats. The curve represents conditions at plats 3 and 4 at Taylorsville when the soil is dry.

bols have been used to indicate the various plats on which the data was secured. Where the ground was wet when the rainfall began the points have been blackened; where it was dry, they have been left white. In one or two instances the experiment number has been placed near the point in order to indicate a different soil condition.

Points representing runs 24 and 34 of table 17, and 2, 3, and 4 of table 19, made at the Taylorsville hill plats in October, have been balanced by a line, since for these runs the soil and surface conditions were practically the same. Points secured at Moraine Park do not cover a sufficient range to determine a curve.

The amount of the surface storage in a given instance is indicated by the height of the hump, or peak, at the end of the retention curve, see figures 13 to 21, inclusive, caused by the draining off of the water after the precipitation ceased. The amounts are small in all cases, as would be expected since there was relatively little vegetation on any of the plats for which mass curves were platted. The quantities vary from practically nothing to about 0.07 of an inch.

CHAPTER V.—MONTHLY, SEASONAL, AND ANNUAL RAINFALL AND RUNOFF

INTRODUCTORY

General information regarding monthly, seasonal, and annual rainfall and runoff, their distribution throughout the year, their extreme variations, and the normal, monthly, seasonal, and annual amounts, are of importance in most hydraulic engineering work.

Criticisms are often made of the method of discussing rainfall and runoff by monthly, seasonal, or annual periods. These, as a rule, are based on the condition that the division date between periods may fall within a time of storm rainfall, or of flood runoff; or that due to snow accumulations, or ground water storage, precipitation during one period may affect the runoff in the following period. These objections, of course, are of more importance as regards studies based on the shorter periods. They also are of more importance with respect to studies of the larger drainage areas, inasmuch as flood runoff on the smaller areas is more nearly coincident with storm rainfall.

Such criticisms are well founded and should be borne in mind. However, they apply principally to theoretical studies of laws governing runoff rather than to particular engineering problems. Because such studies do not lead to the discovery of the laws of runoff is no reason why they should be wholly discontinued.

In making studies of seasonal and annual rainfall and runoff the above objections may be partially met by using the "water year" rather than the calendar year, and by a judicious division of the year into seasons, or periods. Rafter, in his studies of rainfall and runoff,* used the water year ending November 30. He divided the year into three periods, namely, the storage period, including the months from December to May, the growing period, including the months from June to August; and the replenishing period, including the months from September to No-

*The Relation of Rainfall to Runoff, by George W. Rafter, U. S. G. S. Water Supply Paper 80, 1903; also Hydrology of the State of New York, by George W. Rafter, Bulletin 85, New York State Museum.

vember. For conditions in the Miami Valley, the year ending September 30, which has been adopted by the Water Resources Branch of the U. S. Geological Survey, seems to be more satisfactory than the year ending November 30. It also seems better to consider the months from October to December as the replenishing period, the months from January to April as the storage period, and the months from May to September as the growing period.

This chapter will take up the studies of monthly, seasonal, and annual rainfall, runoff, percolation, and evaporation, which have been made for some of the drainage areas in the Miami Valley. A method of showing hydrological conditions by means of mass curves will also be described.

If the amount of water stored in the ground, or on the ground is the same at the beginning and ending of a period of time, the difference between the total rainfall and the total runoff during this period must be equal to the total evaporation, using the term evaporation to include plant transpiration and evaporation of precipitation intercepted by vegetation as well as direct evaporation from soil or water surfaces. Studies of ground water flow indicate that in the Miami Valley variations in the amount of

Table 20.—Stations Used in Studies of Rainfall and Runoff

Station	Stream	Drainage Area	Records Available*
		Square Miles	Years, Inclusive
Sidney	Miami River	555	1915–1919
Lockington	Loramie Creek	255	1916–1919
Piqua	Miami River	842	1912–1919
Tadmor	Miami River	1128	1915–1919
Pleasant Hill	Stillwater River	453	1917–1919
West Milton	Stillwater River	600	1915–1919
Springfield	Buck Creek	163	1915–1919
Springfield	Mad River	488	1915–1919
Wright	Mad River	652	1915–1919
Dayton	Miami River	2525	1894–1919
Franklin	Miami River	2785	1917–1919
Germantown	Twin Creek	272	1915–1919
Seven Mile	Seven Mile Creek	128	1915–1919
Hamilton	Four Mile Creek	178	1915–1919
Hamilton	Miami River	3672	1911–1919

*Years ending September 30.

water in the ground at the end of the water year are relatively small proportions of the yearly evaporation. Consequently, in the following tables and discussions dealing with annual quantities the term evaporation is used to mean the difference between the rainfall and runoff. However, in the studies of seasonal and

monthly values the term retention has been used, since in these cases variations in the amount of water in the ground are comparatively large.

COMPILATION OF THE DATA

Table 20 gives the gaging stations for which the data was compiled, the streams on which they are located, the areas drained, and the period of years for which records are available, the division into years being made on September 30 instead of on December 31. It will be noted that records for full years prior to 1915 are available only for the Piqua, Dayton, and Hamilton stations.

The annual rainfall, runoff, retention, and ratio of runoff to rainfall, were tabulated for all records available, for each station in table 20, except Piqua. On account of unreliable gage height data at Piqua for some of the earlier years and for a part of the year 1918, the quantities were tabulated for the years 1915, 1916, 1917, and 1919 only. The annual, seasonal, and monthly rainfall, runoff, retention, ratio of runoff to rainfall, and temperature had been compiled for the entire record at the Dayton station just before the 1919 data was compiled. Since the 1919 values do not differ materially from the averages based on the 25-year record the studies have not been revised so as to include the 1919 data, except in the case of table 21.

The proportions of annual runoff which appear as surface or flood runoff and as low water or ground water flow, were determined for the Dayton, Wright, West Milton, and Buck Creek stations. The Dayton station was chosen because of its comparatively long record and because it is representative of the average conditions throughout the Miami Valley. The other stations were chosen because a cursory examination of the records, as well as the study of flood runoff given in the following chapters, indicated that the surface runoff from their drainage areas varies considerably. Mass curves were drawn only for the drainage area of Mad River above Wright.

The annual, seasonal, and monthly rainfall given in the tabulations are averages over the drainage areas above the stations, not the amounts recorded at the stations themselves; and are for the years ending September 30, rather than for the calendar years. For the years 1915 to 1919, inclusive, the annual amounts were determined by planimeter measurements on maps showing lines of equal annual rainfall. The annual, seasonal, and monthly

Table 21.—Annual Rainfall, Runoff, and Evaporation in the Miami Valley

Stations	Rainfall Inches	Runoff Inches	Ratio of Runoff to Rainfall per cent	Evaporation Inches	Rainfall Inches	Runoff Inches	Ratio of Runoff to Rainfall per cent	Evaporation Inches	Rainfall Inches	Runoff Inches	Ratio of Runoff to Rainfall per cent	Evaporation Inches
	1915				1916				1917			
Sidney	40.4	12.2	30.2	28.2	38.3	19.4	50.6	18.9	35.2	8.98	25.5	26.2
Lockington	41.2	......	......	......	37.9	20.8	54.9	17.1	35.0	13.8	39.4	21.2
Piqua	41.0	14.3	34.9	26.7	38.4	19.6	51.9	18.8	35.2	10.4	29.6	24.8
Tadmor	41.7	13.5	32.4	28.2	39.1	19.7	50.4	19.4	35.3	11.9	33.7	23.4
Pleasant Hill	44.8	......	......	......	37.3	......	......	......	38.3	13.6	35.5	24.7
West Milton	43.7	12.6	28.8	31.1	37.6	17.6	46.8	20.0	37.1	12.3	33.2	24.8
Buck Creek	40.1	8.3	20.7	31.8	42.2	14.8	35.1	27.4	34.2	10.2	29.8	24.0
Springfield	41.2	11.5	27.9	29.7	43.8	17.4	39.7	26.4	36.6	12.0	32.8	24.6
Wright	40.8	12.0	29.4	28.8	42.8	19.4	45.3	23.4	36.4	13.5	37.1	22.9
Dayton	41.8	12.1	28.9	29.7	39.9	19.2	48.1	20.7	35.7	11.4	31.9	24.3
Franklin	41.8	......	......	......	39.8	......	......	......	35.8	11.9	33.2	23.9
Germantown	41.6	15.8	38.0	25.8	38.6	18.6	48.2	20.0	37.4	13.7	36.6	23.7
Seven Mile	41.6	17.5	42.1	24.1	39.1	23.5	60.1	15.6	39.0	17.0	43.6	22.0
Four Mile	41.0	16.3	39.7	24.7	39.6	24.8	62.6	14.8	38.0	13.8	36.3	24.2
Hamilton	41.7	11.2	26.9	30.5	39.8	18.8	47.2	21.0	36.4	11.6	31.9	24.8
	1918				1919				Average			
Sidney	35.1	9.1	25.9	26.0	32.8	9.0	27.4	23.8	36.3	11.7	32.2	24.6
Lockington	33.7	8.7	25.8	25.0	30.9	......	......	......	35.8	13.3	37.2	22.5
Piqua	34.8	......	......	......	32.3	9.4	29.1	22.9	36.4	12.6	34.6	23.8
Tadmor	36.0	9.2	25.5	26.8	33.1	11.5	34.7	21.6	37.0	13.2	35.7	23.8
Pleasant Hill	35.2	10.1	28.7	25.1	33.4	12.5	37.4	20.9	37.8	13.3	35.2	24.5
West Milton	35.4	13.3	37.6	22.1	33.5	12.0	34.0	22.1	37.5	13.6	36.3	23.9
Buck Creek	38.8	10.1	26.0	28.7	37.6	11.0	29.3	26.6	38.6	10.8	28.0	27.8
Springfield	38.6	10.5	27.2	28.1	38.5	12.8	33.2	25.7	39.7	12.8	32.2	26.9
Wright	39.2	11.1	28.3	28.1	38.1	12.9	33.9	25.2	39.5	13.8	34.9	25.7
Dayton	36.8	9.4	25.6	27.4	34.6	11.2	32.4	23.4	37.8	12.6	33.3	25.2
Franklin	36.9	8.9	24.1	28.0	34.6	11.2	32.4	23.4	37.8	12.6	33.3	25.2
Germantown	39.5	12.1	30.7	27.4	34.5	12.9	37.4	21.6	38.3	14.7	38.4	23.6
Seven Mile	43.4	21.9	50.5	21.5	34.1	17.1	50.1	17.0	39.5	19.4	49.1	20.1
Four Mile	41.6	10.6	25.5	31.0	35.4	10.7	30.2	24.7	39.2	15.3	39.0	23.9
Hamilton	37.9	9.6	25.3	28.3	34.5	11.5	33.3	23.0	38.0	12.5	32.9	25.5

rainfall for years prior to 1915, and the seasonal and monthly values for the years 1915 to 1918, where it was only necessary to obtain data for the Dayton and Hamilton stations, were obtained by averaging directly the records of all stations on the given drainage areas. While the latter method does not consider the distribution of stations, comparisons of the results obtained, with those obtained by the planimeter measurements, showed that for such large areas and with so many stations, the results by the shorter method are not appreciably in error.

The values of annual, seasonal, and monthly runoff were calculated from the daily stream flow records, except in the case of the 1911 and 1912 records at Hamilton. These were obtained from the U. S. Geological Survey water supply papers, proper corrections being made for the flow in the Miami and Erie Canal, which is not included in the government data.

In the studies of the relation of temperature to runoff the records at the Dayton co-operative station were utilized. It was not considered necessary to calculate the average temperature over the drainage area, inasmuch as any difference which may exist tends to be constant in amount, algebraically as well as arithmetically, and also tends to be relatively small.

The method of estimating the proportions of annual runoff which appear as surface or flood flow and as low water or ground water flow, and the method of drawing mass curves, will be described later.

ANNUAL RAINFALL AND RUNOFF

Records for Years 1915-1919

Table 21 gives the annual rainfall, runoff, ratio of runoff to rainfall, and evaporation for all stations at which stream flow records are being compiled, for the years 1915 to 1919, inclusive. The average values, although very uncertain due to the shortness of the period, are also included. Studies based on the 25-year record at the Dayton station, discussed later, show that no one of these years was greatly different from normal. In order that the average values should be comparable throughout, missing records at the Lockington, Piqua, Pleasant Hill, and Franklin stations were estimated from the data at adjacent stations and were included in the calculation of averages.

An inspection of the table shows that the runoff in the Miami Valley is, on the average, about one-third of the rainfall. The runoff from the Buck Creek drainage area seems to be somewhat

less than in the other parts of the Mad River Valley. The total runoff from the Mad River drainage area, as shown by the records at the Wright station, is the same as the total runoff from the Stillwater River Valley, as shown by the West Milton records. The runoff in the upper Miami Valley seems to be practically the same as the runoff in the Mad and Stillwater drainage areas. The runoff in the Twin, Seven Mile, and Four Mile Creek areas, southwest of Dayton, seems to be higher than in the other parts of the valley. However, the records at these stations are somewhat more uncertain than those at the other stations, due to the greater difficulties encountered in obtaining the stream flow data; and it is doubtful if the runoff is actually much different from that of the other parts of the Miami Valley. The records at Hamilton, which are very satisfactory, seem to bear out this conclusion since they agree substantially with the Dayton records.

The runoff during the year 1916 was comparatively high, and the evaporation comparatively low, due to the large amount of storm rainfall that fell during the months of January, February, and March, when the available surface and ground storage was a minimum and the evaporation rate insignificant.

Records Above Hamilton

Table 22 gives the annual rainfall, runoff, evaporation, and ratio of runoff to rainfall, for the Hamilton station. Averages of the various quantities and departures from the averages are also given; and the maximum and minimum records are set in bold face type.

The rainfall records are accurate throughout. The maximum error for a single year probably does not exceed two per cent. The runoff and evaporation records are believed to be fairly accurate for all years except 1912. The runoff of 15.6 inches given for 1912 is believed to be considerably too low, inasmuch as the record for Dayton, for the same year is 23.1 inches. The Dayton record is probably too high. There seems to be no reason why the amounts at these two stations should be so different. The records for the years 1915 to 1919, inclusive, agree very well, as previously mentioned. The rainfall during the year 1912 was about the same as in 1913 but was much more uniformly distributed throughout the year. Consequently the runoff would be expected to be greater than normal but less than in 1913. Probably the average of the two records, 19.3 inches,

Table 22.—Annual Rainfall, Runoff, and Evaporation in the Miami Valley above Hamilton

Year Ending September 30	Rainfall			Runoff			Ratio of Runoff to Rainfall per cent	Evaporation		
	Inches	Per cent of Average	Departure from Average in per cent	Inches	Per cent of Average	Departure from Average in per cent		Inches	Per cent of Average	Departure from Average in per cent
1911	39.6	102.1	+2.1	13.5	95.9	—4.1	34.1	26.1	105.6	+5.6
1912	**43.4**	**111.9**	+11.9	15.6	110.8	+10.8	35.9	27.8	112.5	+12.5
1913	43.2	111.4	+11.4	**24.4**	**173.3**	+73.3	56.4	**18.8**	**76.1**	—23.9
1914	**32.6**	**84.0**	—16.0	10.5	74.6	—25.4	32.2	22.1	89.4	—10.6
1915	41.7	107.5	+7.5	11.2	79.6	—20.4	26.9	**30.5**	**123.4**	+23.4
1916	39.8	102.6	+2.6	18.8	133.5	+33.5	47.2	21.0	85.0	—15.0
1917	36.4	93.8	—6.2	11.6	82.4	—17.6	31.9	24.8	100.4	+0.4
1918	37.9	97.7	—2.3	**9.6**	**68.2**	—31.8	25.3	28.3	114.5	+14.5
1919	34.5	89.0	—11.0	11.5	81.7	—18.3	33.3	23.0	93.1	— 6.9
Average	38.79	100.0	7.89	14.08	100.0	26.13	36.3	24.71	100.0	12.53

is about the true value. Assuming this figure to be correct the evaporation for 1912 would be reduced from 27.8 inches to 24.1 inches.

Owing to the insufficiency of the stream flow records, the runoff for the year 1913 has been assumed to be the same as at Dayton, an assumption probably not much in error since the runoff at Dayton was well determined.

While the period of record, only nine years, is too short to give very satisfactory information, the data seems to show that the runoff is the most variable quantity of the three and that the rainfall is the least variable. The average departure of the annual runoff from the mean value is seen to be 26.1 per cent; the average departure of the annual evaporation, 12.5 per cent; and the average departure of the annual rainfall, only 7.9 per cent. A considerably greater value for the average departure of annual rainfall was obtained for the Miami Valley above Dayton, where records for 25 years are available, as will be discussed later. The maximum annual rainfall is seen to be 1.12 times the mean and 1.33 times the minimum; the maximum annual runoff, 1.73 times the mean and 2.54 times the minimum; and the maximum annual evaporation, 1.23 times the mean and 1.62 times the minimum.

The average ratio of runoff to rainfall is seen to be 36.3 per cent, or slightly greater than one-third. The maximum value occurred during the year 1913, probably due to the memorable flood of that year. Although the ratio was unusually low in 1915, when the evaporation was a maximum due to the large amount of storm rainfall occurring during the summer months, the actual minimum value occurred in 1918, amounting to only 25.3 per cent.

Records Above Dayton

Table 23 gives the annual rainfall, runoff, evaporation, temperature, and ratio of runoff to rainfall, for the years 1894 to 1918, inclusive, at the Dayton station, 25 years in all. Averages of the various quantities and departures from the averages are given as in table 22; and the maximum and minimum values are set in bold face type. The ratios of the maximum quantities to the mean and minimum quantities are also included.

The rainfall and temperature records are fairly satisfactory throughout. The runoff and evaporation records are more reliable during the years 1905 to 1918, inclusive, than they are dur-

Table 23.—Annual Rainfall, Runoff, Evaporation, and Temperature over the drainage area above Dayton

Year Ending September 30	Rainfall			Runoff			Ratio of Runoff to Rainfall in per cent	Evaporation*			Temperature**		
	Inches	Per cent of Average	Departure from Average in per cent	Inches	Per cent of Average	Departure from Average in per cent		Inches	Per cent of Average	Departure from Average in per cent	Degrees F	Per cent of Average	Departure from Average in per cent
1894	30.7	82.8	—17.2	4.9	41.3	—58.7	16.0	25.8	102.4	+2.4	54.7	103.7	+ 3.7
1895	**24.0**	**64.8**	—35.2	**3.7**	**31.2**	—68.8	15.4	20.3	80.6	—19.4	53.0	100.5	+ 0.5
1896	**46.2**	**124.6**	+24.6	8.1	68.2	—31.8	17.5	38.1	**151.2**	+51.2	54.0	102.4	+ 2.4
1897	33.3	89.8	—10.2	12.8	107.8	+ 7.8	38.4	20.5	81.4	—18.6	53.4	101.1	+ 1.2
1898	44.3	119.5	+19.5	14.7	123.8	+23.8	33.2	29.6	117.4	+17.4	**55.0**	**104.2**	+ 4.2
1899	34.2	92.3	— 7.7	9.7	81.7	—18.3	28.4	24.5	97.2	— 2.8	53.2	100.8	+ 0.8
1900	35.1	94.7	— 5.3	6.6	55.6	—44.4	18.8	28.5	113.1	+13.1	54.4	103.1	+ 3.1
1901	30.1	81.2	—18.8	5.6	47.2	—52.8	18.6	24.5	97.2	— 2.8	53.4	101.2	+ 1.2
1902	31.6	85.2	—14.8	3.8	32.0	—68.0	**12.0**	27.8	110.3	+10.3	51.1	96.8	— 3.2
1903	37.1	100.1	+ 0.1	12.6	106.1	+ 6.1	34.0	24.5	97.2	— 2.8	53.6	101.6	+ 1.6
1904	39.1	105.5	+ 5.5	13.1	110.3	+10.3	33.5	26.0	103.2	+ 3.2	49.8	94.4	— 5.6
1905	38.5	103.9	+ 3.9	7.1	59.8	—40.2	18.4	31.4	124.6	+24.6	51.5	97.6	— 2.4
1906	33.2	89.6	—10.4	9.2	77.5	—22.5	27.7	24.0	95.2	— 4.8	52.9	100.2	+ 0.2
1907	43.1	116.3	+16.3	17.2	144.9	+44.9	39.9	25.9	102.8	+ 2.8	51.9	98.4	— 1.6
1908	37.7	101.7	+ 1.7	17.7	149.1	+49.1	46.9	20.0	79.4	—20.6	53.1	100.6	+ 0.6
1909	39.3	106.0	+ 6.0	13.1	110.3	+10.3	33.3	26.2	104.0	+ 4.0	53.2	100.8	+ 0.8
1910	36.3	97.9	— 2.1	15.1	127.2	+27.2	41.6	21.2	84.1	—15.9	52.3	99.1	— 0.9
1911	39.8	107.4	+ 7.4	13.9	117.1	+17.1	34.9	25.9	102.8	+ 2.8	53.7	101.7	+ 1.7
1912	43.8	118.2	+18.2	23.1	194.6	+94.6	52.7	20.7	82.2	—17.8	50.8	96.3	— 3.7
1913	42.9	115.7	+15.7	**24.4**	**205.5**	+105.5	**56.9**	**18.5**	**73.4**	—26.6	54.0	102.4	+ 2.4
1914	32.3	87.1	—12.9	8.3	69.9	—30.1	25.7	24.0	95.2	— 4.8	53.3	101.0	+ 1.0
1915	41.8	112.8	+12.8	12.1	101.9	+ 1.9	28.9	29.7	117.8	+17.8	52.1	98.7	— 1.3
1916	39.9	107.6	+ 7.6	19.2	161.7	+61.7	48.1	20.7	82.2	—17.8	53.2	100.8	+ 0.8
1917	35.7	96.3	— 3.7	11.4	96.0	— 4.0	31.9	24.3	96.4	— 3.6	51.1	96.8	— 3.2
1918	36.8	99.3	— 0.7	9.4	79.2	—20.8	25.5	27.4	108.7	+ 8.7	50.3	95.4	— 4.6
Average	37.07	100.0	11.13	11.87	100.0	36.83	32.04	25.20	100.0	12.66	52.76	100.0	2.11
Max. ÷ Ave.	1.25	....	....	2.05	....	....	....	1.51	....	....	1.04	....	....
Max. ÷ Min.	1.92	....	....	6.60	....	....	....	2.06	....	....	1.10	....	....

*Taken equal to the difference between the rainfall and the runoff.
**Determined from recorda of the Dayton Cooperative Station.

ing the earlier years, although the data for 1912 is probably in error, as previously mentioned.

Figure 27 shows the total runoff, rainfall, and evaporation, in inches, and the average temperature in degrees Fahrenheit, for each year; also the mean annual values. Figure 28 shows the annual departures of the various quantities.

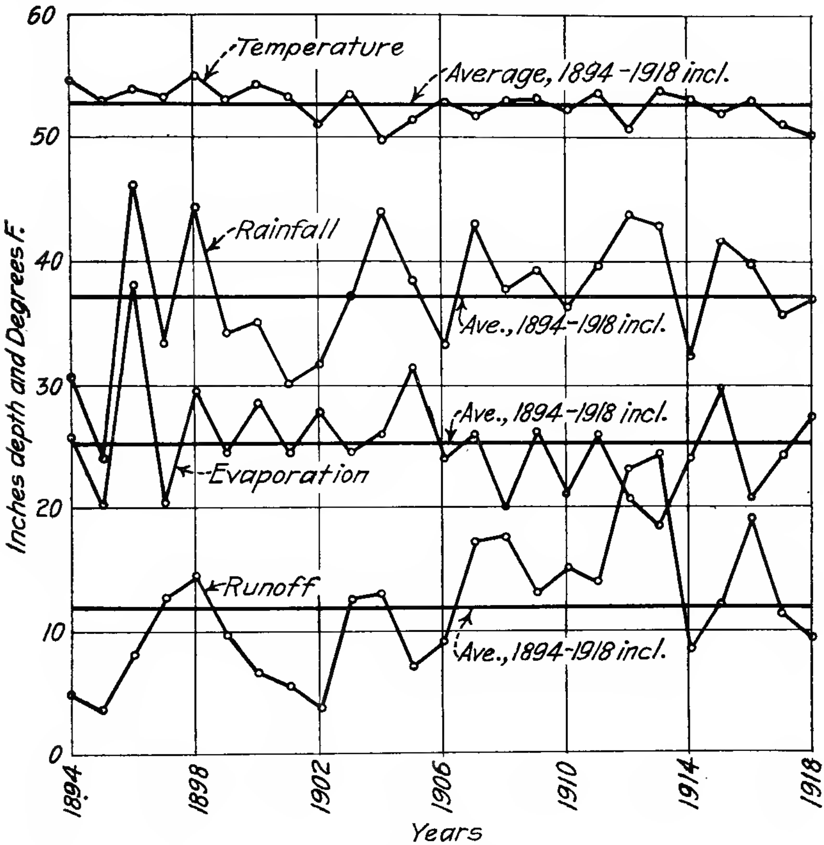

FIG. 27.—ANNUAL RAINFALL, RUNOFF, EVAPORATION, AND TEMPERATURE ABOVE DAYTON.

The horizontal lines indicate the mean annual values of the various quantities.

Table 23 shows that the mean annual rainfall is 37.07 inches; the mean annual runoff, 11.87 inches; the ratio of mean annual runoff to mean annual rainfall, 32.04 per cent, or slightly less than one-third; the mean annual evaporation, 25.20 inches; and the mean annual temperature, 52.76 degrees Fahrenheit. The

average departure of the annual rainfall is seen to be 11.13 per cent; of the runoff, 36.83 per cent; of the evaporation, 12.66 per cent; and of the temperature, 2.11 per cent. These figures show that the runoff is much more variable than either the rainfall or the evaporation, that the rainfall is only slightly less variable than the evaporation, a condition somewhat different from that shown by the 9-year record at Hamilton, and that the temperature is much less variable than any of the other quantities.

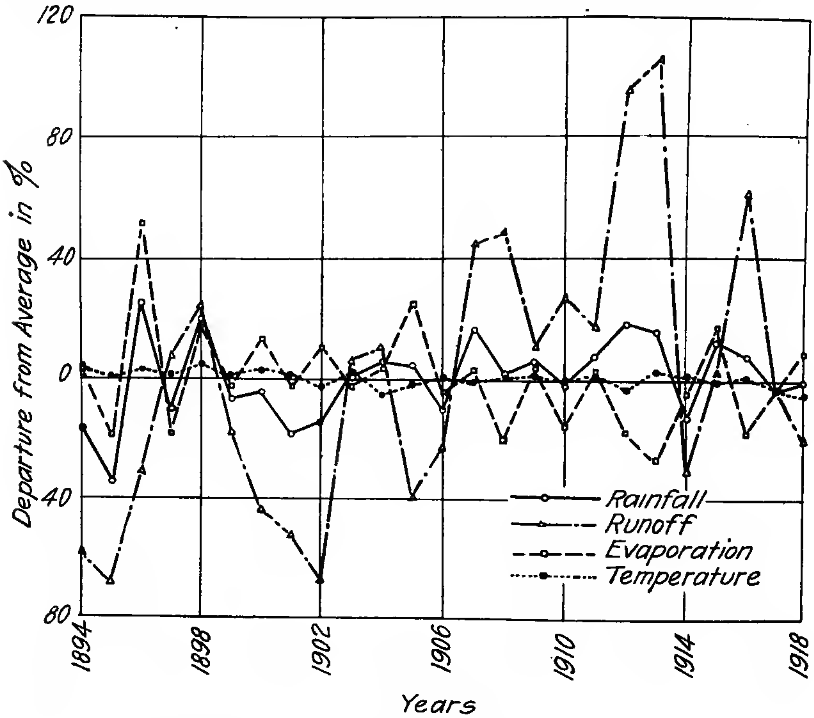

FIG. 28.—DEPARTURES OF ANNUAL RAINFALL, RUNOFF, EVAPORATION, AND TEMPERATURE ABOVE DAYTON.

The theory that the annual evaporation is a relatively constant quantity, which has been advanced by some engineers, does not appear to be true for the Miami Valley. The reason evaporation is variable is that the rainfall is variable. In order for the evaporation to be constant it would be necessary for the rainfall to be constant in distribution throughout the year as well as in quantity; inasmuch as the transpiration, which constitutes the greater part of the annual evaporation, varies with the amount of water available during the growing season. The variations

in annual evaporation probably decrease in importance as the proportion of the drainage area covered by water surfaces increases.

In figure 29 the runoff and evaporation departures have been platted as ordinates against the rainfall departures as abscissas. These diagrams seem to indicate that the runoff is generally

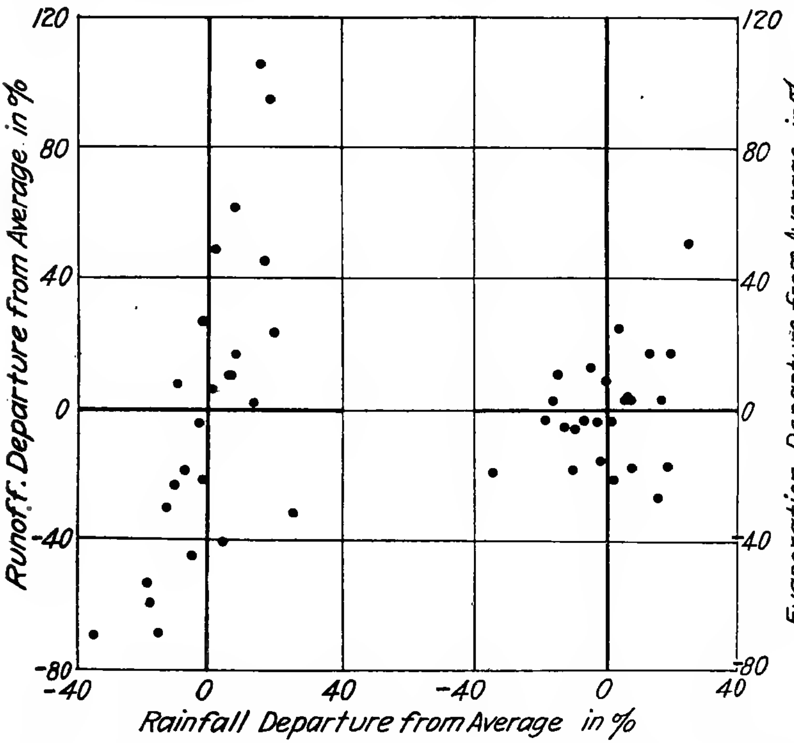

FIG. 29.—RELATIONS BETWEEN ANNUAL RAINFALL, RUNOFF, AND EVAPORATION ABOVE DAYTON.

Departures of annual runoff and evaporation are platted as ordinates against the departures of annual rainfall as abscissas.

greater than normal when the rainfall is greater than normal and vice versa; also that runoff is a more variable quantity than either rainfall or evaporation.

The maximum annual rainfall is seen to be 1.25 times the mean and 1.92 times the minimum; the maximum annual runoff, 2.05 times the mean and 6.60 times the minimum; the maximum annual evaporation, 1.51 times the mean and 2.06 times the min-

imum; and the maximum annual temperature, 1.04 times the mean and 1.10 times the minimum.

The minimum annual rainfall occurred during the year 1895, amounting to 24.0 inches, or about 65 per cent of the mean annual. The minimum annual runoff occurred during the same year and amounted to 3.7 inches, or about 31 per cent of the mean annual. While the runoff records for the years 1894 to 1904 are not so accurate as they are for the later years, the value of 3.7 inches in 1895 is checked, in a way, by the record of only 4.9 inches for the same year for the Muskingum drainage area above Zanesville, where the topography is slightly more rugged than in the Miami Valley.*

The maximum rainfall occurred in 1896, following the year of minimum rainfall, and amounted to 46.2 inches, or about 25 per cent more than normal. The runoff in 1896 was only 8.1 inches, or about 68 per cent of the normal amount; and the evaporation was 38.1 inches, or about 51 per cent more than normal, being the maximum for the entire record. However, this is an instance where the error due to the division into annual periods may have an appreciable value. Figure 30 shows the total rainfall on the drainage area above Dayton for each month of each year from 1894 to 1918, inclusive; and also the average for each month calculated from the 25 separate values. The rainfall during the months of July, August, and September, 1896, is seen to have been considerably greater than normal, amounting to 8.94, 5.06, and 6.13 inches, respectively. Consequently a part of this precipitation may have percolated through the surface soil; and, instead of being evaporated, appeared later, as ground water runoff. The study of monthly runoff, given later, shows that this delayed runoff probably did not exceed an inch. Assuming this figure to be correct the evaporation would be decreased to 37.1 inches in 1896, an amount still greater than any other annual amount, and increased to 21.5 inches in 1897; the runoff would be increased to 9.1 inches in 1896 and decreased to 11.8 inches in 1897; and the ratio of runoff to rainfall would be increased to 19.7 in 1896 and decreased to 35.4 in 1897. The unusual evaporation during the year 1896 was undoubtedly due to the large amount of storm rainfall that fell during the summer months when the plant requirements were a maximum.

The maximum runoff occurred in 1913, and amounted to 24.4 inches, or about 105 per cent more than normal. The minimum

*See U. S. Geological Survey Water Supply Paper 80, by George W. Rafter, 1903, page 85.

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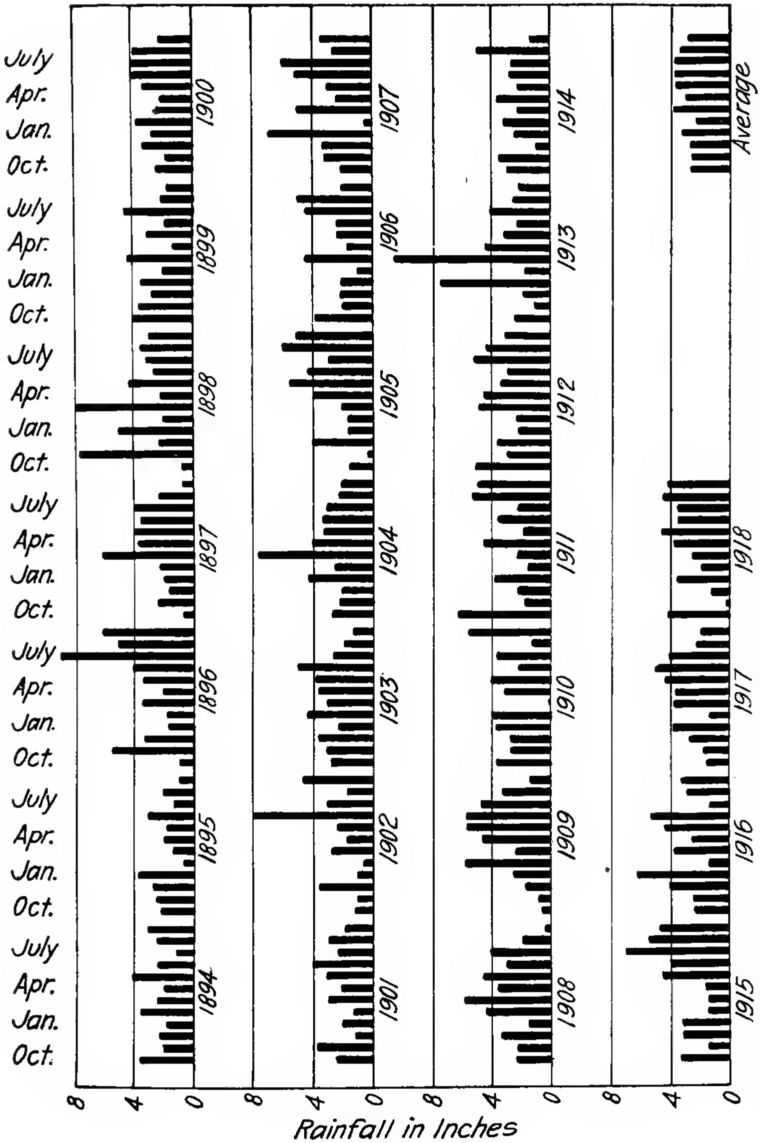

FIG. 30.—MONTHLY RAINFALL OVER THE DRAINAGE AREA ABOVE DAYTON.
The mean monthly values based on the 25 years records are given in the lower right hand corner.

evaporation occurred during the same year, amounting to 18.5 inches or about 27 per cent less than normal. The large runoff and small evaporation in 1913 was undoubtedly due to the large amount of storm rainfall that fell during the months of January and March, when the conditions were most favorable for high rates of surface runoff.

A period of low rainfall and runoff occurred during the years 1899 to 1902, inclusive. During this time the amount of runoff gradually decreased until in 1902 it was only 3.8 inches, or only 0.1 of an inch greater than the minimum for the entire record. The minimum ratio of runoff to rainfall occurred during this year, amounting to only 12.0 per cent. In fact, a study of the data in table 23 seems to indicate that the ratio of runoff to rainfall is generally lower, as might be expected, during the dry periods than it is during the wet periods.

That variations in the amount of annual runoff and evaporation are due principally to the distribution of rainfall throughout the year rather than to the amount of the rainfall is indicated by the preceding discussion of conditions during the years 1896 and 1913. A study of figures 27, 28, and 30 leads to further corroboration of this conclusion. During the year 1914, when the rainfall was 32.3 inches, or about 13 per cent less than normal, the runoff was only 8.3 inches, or about 30 per cent less than normal, and the evaporation was 24.0 inches, or only about 5 per cent less than normal, due to the comparatively uniform distribution of the rainfall throughout the year. In 1915, the rainfall was 41.8 inches, or about 13 per cent more than normal; and was comparatively heavy during the summer months, when transpiration, surface and soil storage were comparatively great. Consequently the evaporation was 29.7 inches, or about 18 per cent more than normal, while the runoff was only 12.1 inches or about 2 per cent more than normal. In 1916, when the rainfall was 39.9 inches, or only about 8 per cent more than normal, the runoff was 19.2 inches, or about 62 per cent more than normal, and the evaporation was only 20.7 inches, or about 18 per cent less than normal, due to the large amount of precipitation that occurred as storm rainfall, principally during the winter months. The conditions during other years might be described but those already mentioned are probably sufficient to indicate the importance of rainfall distribution.

The three diagrams in figure 31 show the annual rainfall, runoff and evaporation departures, respectively, platted as ordi-

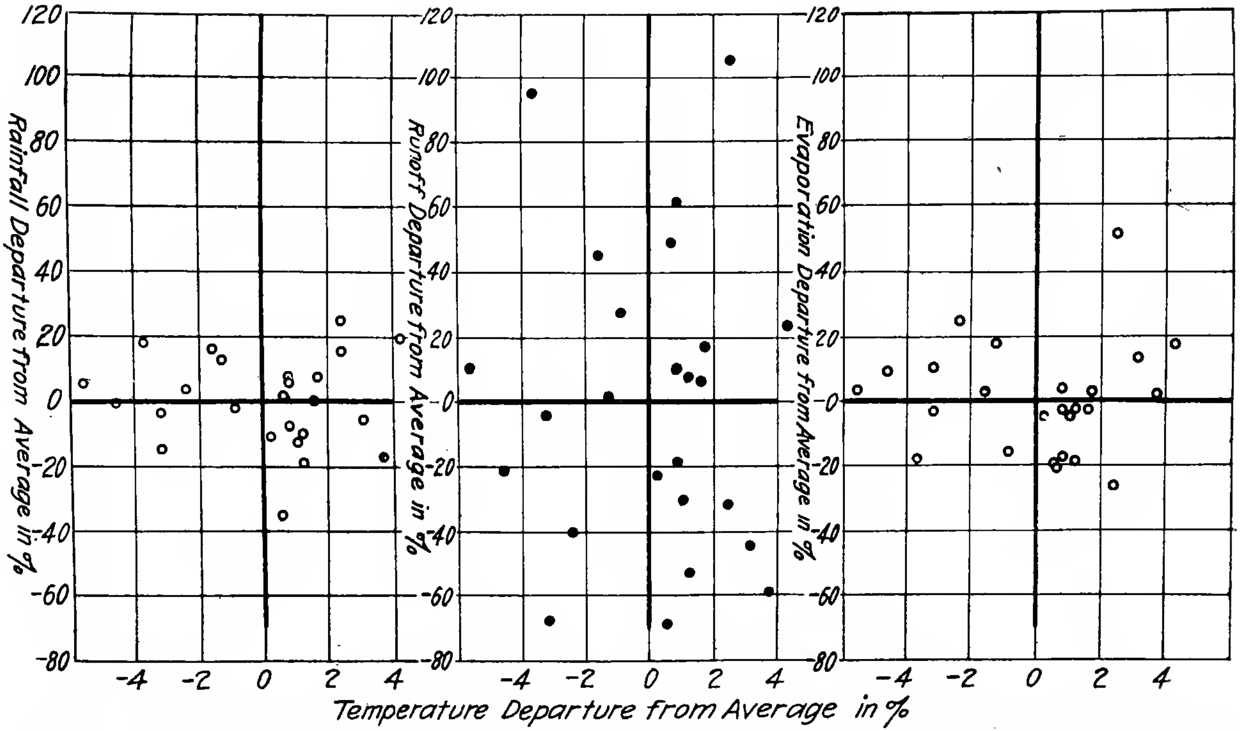

FIG. 31.—EFFECT OF TEMPERATURE ON ANNUAL RAINFALL, RUNOFF, AND EVAPORATION ABOVE DAYTON.

The departure of annual rainfall, runoff, and evaporation are platted as ordinates against the departure of annual temperature as abscissas.

nates against the annual temperature departures as abscissas. No definite relation seems to be shown by any of these diagrams. The variations in annual temperature are so small that whatever effect they may have on rainfall, runoff, or evaporation are not of sufficient magnitude to become noticeable.

SEASONAL RAINFALL AND RUNOFF

Table 24 gives the seasonal rainfall, runoff, retention, temperature, and ratio of runoff to rainfall for the drainage area of the Miami River above Dayton. The year is divided into three seasons, or periods, as they are generally termed; the replenishing, storage, and growing periods. The replenishing period includes the months of October, November, and December; the storage period, the months of January, February, March, and April; and the growing period, the months of May, June, July, August, and September.

Averages of the various quantities for the twenty-five years of record are included in the table; and the maximum and minimum values are set in bold face type. The ratios of the maximum to the mean and minimum quantities are also given. The data is shown graphically in figure 32.

The mean values given near the bottom of table 24 show that on the average the rainfall is about 7.69 inches, or about 21 per cent of the mean annual, during the replenishing period; about 12.23 inches, or 33 per cent of the mean annual, during the storage period; and about 17.13 inches, or 46 per cent of the mean annual, during the growing season. The average runoff appears to be about 1.69 inches, or 14 per cent of the mean annual, during the replenishing period; about 7.22 inches, or 61 per cent of the mean annual, during the storage period; and about 2.96 inches, or 25 per cent of the mean annual, during the growing period. The average retention appears to be about 6.00 inches, or 24 per cent of the mean annual, during the replenishing period; about 5.01 inches, or 20 per cent of the mean annual, during the storage period; and about 14.17 inches, or 56 per cent of the mean annual, during the growing season. The mean temperature is 43.1 degrees Fahrenheit, during the replenishing period, 38.2 degrees during the storage period, and 70.3 degrees during the growing period, the mean annual being 52.76 degrees, as previously mentioned. It is interesting to note the comparatively high retention and low runoff during the growing season

Table 24.—Seasonal Rainfall, Runoff, Retention, and Temperature above Dayton

Year Ending September 30	Replenishing Period					Storage Period					Growing Period				
	Rainfall in Inches	Runoff in Inches	Retention in Inches	Ratio Runoff Rainfall per cent	Temperature in Degrees F	Rainfall in Inches	Runoff in Inches	Retention in Inches	Ratio Runoff Rainfall per cent	Temperature in Degrees F	Rainfall in Inches	Runoff in Inches	Retention in Inches	Ratio Runoff Rainfall per cent	Temperature in Degrees F
1894	8.00	.82	7.18	10.2	43.5	9.62	2.67	6.95	27.7	**41.8**	13.05	1.43	11.62	11.0	71.6
1895	7.32	.76	6.56	10.4	42.0	7.60	1.88	5.72	24.7	37.0	**9.11**	**1.08**	**8.03**	11.8	72.5
1896	9.87	.87	9.00	8.8	42.8	8.96	3.04	5.92	33.9	40.4	**27.42**	4.16	**23.26**	15.2	71.7
1897	4.89	2.57	2.32	**52.6**	44.7	14.03	7.20	6.83	51.3	39.7	14.36	3.01	11.35	21.0	69.8
1898	10.74	1.65	**9.09**	15.4	46.2	17.08	10.23	6.85	59.9	40.9	16.46	2.82	13.64	17.1	71.5
1899	10.29	2.37	7.92	23.0	42.3	10.87	5.70	5.17	52.4	37.7	13.01	1.64	11.37	12.6	72.1
1900	7.26	.79	6.47	10.9	45.4	10.71	3.91	6.80	36.5	37.6	17.16	1.88	15.28	11.0	**73.2**
1901	7.49	1.15	6.34	15.4	**46.3**	8.30	2.83	5.47	34.1	36.1	14.32	1.67	12.65	11.7	71.5
1902	5.72	**.56**	5.16	9.8	40.4	**6.21**	**1.38**	4.83	**22.2**	36.1	19.68	1.81	17.87	**9.2**	69.7
1903	9.35	2.58	6.77	27.6	45.8	13.26	7.89	5.37	59.4	39.6	14.52	2.10	12.42	14.4	69.6
1904	6.91	.86	6.05	12.4	39.9	18.39	10.20	8.19	55.5	33.6	13.82	2.05	11.77	14.8	68.7
1905	5.61	.59	5.02	10.5	41.6	9.14	2.21	6.93	24.2	35.9	23.73	4.30	19.43	18.1	69.9
1906	7.82	1.78	6.04	22.7	42.9	9.20	5.59	3.61	60.8	37.6	16.15	1.78	14.37	11.0	71.2
1907	8.49	2.00	6.49	23.6	43.1	14.56	10.19	4.37	70.0	39.0	20.03	4.93	15.10	24.6	67.6
1908	8.00	2.12	5.88	26.5	41.6	15.47	11.88	3.59	76.8	39.6	14.19	3.72	10.47	26.2	70.8
1909	**3.16**	.91	**2.25**	28.8	44.5	15.33	6.34	**8.99**	41.3	40.3	20.82	5.83	14.99	**28.0**	68.8
1910	9.06	2.67	6.39	29.5	42.5	10.70	10.22	0.48	95.4	39.9	16.50	2.23	14.27	13.5	68.2
1911	10.18	4.19	5.99	41.1	40.9	11.98	7.06	4.92	58.9	40.3	17.69	2.67	15.02	15.1	72.3
1912	**11.43**	**5.63**	5.80	49.3	43.2	13.71	13.81	**—0.10**	**100.7**	**32.8**	18.70	3.64	15.06	19.5	69.8
1913	5.18	.89	4.29	17.2	44.6	**23.88**	**20.89**	2.99	87.5	39.8	13.82	2.58	11.24	18.7	70.9
1914	7.25	.82	6.43	11.3	45.6	11.27	5.93	5.34	52.6	36.9	13.64	1.56	12.08	11.4	71.0
1915	7.95	.94	7.01	11.8	43.5	7.74	5.06	2.68	65.4	39.0	25.53	**6.10**	19.43	23.9	67.7
1916	8.73	3.08	5.65	35.3	44.9	13.76	12.05	1.71	87.5	38.4	17.06	4.13	12.93	24.2	70.1
1917	6.07	.84	5.23	13.8	42.9	12.45	6.55	5.90	52.6	37.8	17.73	4.06	13.67	22.9	**66.6**
1918	5.53	.93	4.60	16.8	**36.6**	11.54	5.71	5.83	49.5	36.3	19.82	2.79	17.03	14.1	69.7
Average	7.69	1.69	6.00	22.0	43.1	12.23	7.22	5.01	59.1	38.2	17.13	2.96	14.17	17.3	70.3
Max. ÷ Ave.	1.49	3.33	1.51	......	1.07	1.95	2.89	1.79	......	1.10	1.60	2.06	1.65	......	1.04
Max. ÷ Min.	3.62	10.0	4.04	......	1.27	3.14	15 1	......	......	1.28	3.01	5.64	2.91	......	1.10

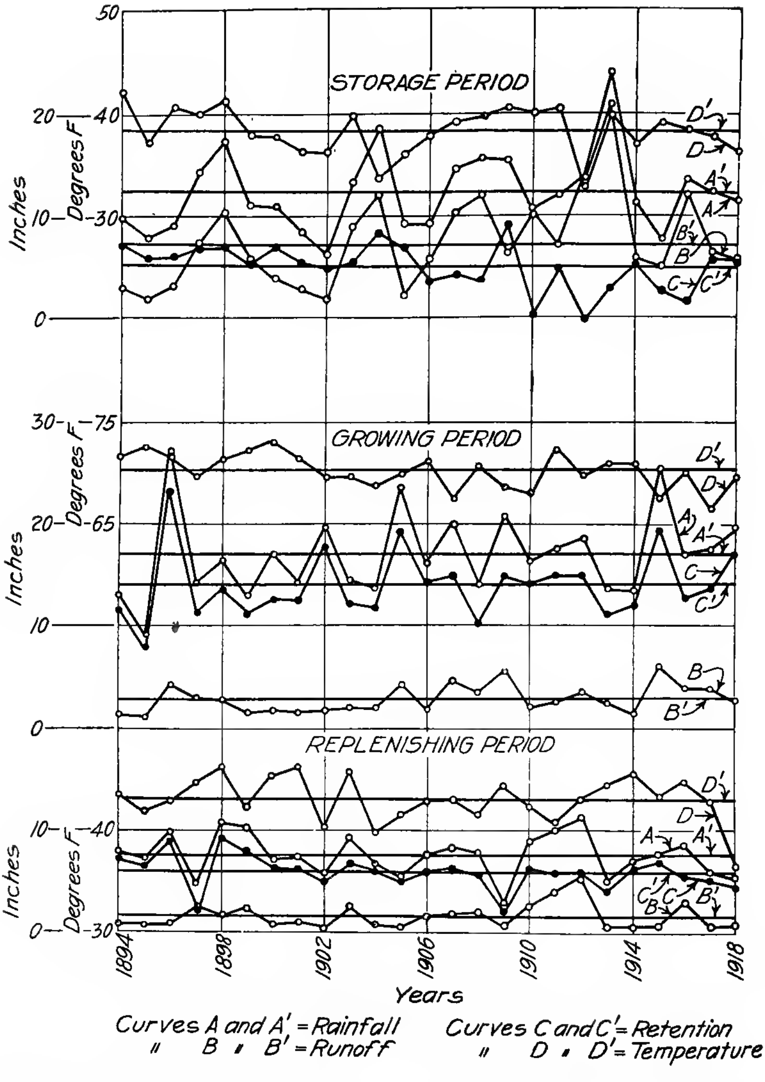

FIG. 32.—SEASONAL RAINFALL, RUNOFF, RETENTION, AND TEMPERATURE ABOVE DAYTON.

The storage period includes the months of January to April; the growing period, the months of May to September; and the replenishing period, the months of October to December. Curves A', B', C', and D' represent mean values for the 25 years of record.

and the comparatively low retention and high runoff during the storage season.

By making proper allowance for the drying out of the surface soil and for the maintenance of stream flow by ground water storage it is possible to estimate the total amount of evaporation during the growing period. The Moraine Park data, described in chapter III, indicates that the amount of moisture in the soil is reduced about 5 inches by transpiration and soil evaporation during the summer. If it is assumed that no percolation occurs during the growing period and that two-thirds of the stream flow during this time is surface runoff, assumptions which are believed to be reasonably correct for the Miami Valley, the evaporation during the growing season would be about 20 inches, or about 80 per cent of the mean annual evaporation. This would leave about 5 inches to be evaporated during the 7 months included in the replenishing and storage periods, corresponding to an average rate of about three-quarters of an inch per month which seems reasonable for the months of October to April, inclusive.

A comparison of the data in table 24 with that given in table 23 shows that the seasonal values are more variable than the annual values in practically all cases, as would naturally be expected. This is shown by the ratio of the maximum quantities to the mean and minimum values as well as by a study of the individual records. The ratios seem to indicate that the runoff during the growing season is slightly more constant than the total annual runoff. However, a study of the departures from the normal runoff for the growing period, not included herein, shows the annual runoff to be slightly more constant. The runoff seems to be more variable than either the rainfall or the retention, in all cases.

Replenishing Period

The maximum rainfall and the maximum runoff during the replenishing period, 11.43 and 5.63 inches respectively, both occurred in 1912, when the annual rainfall was considerably greater than normal. The maximum retention, amounting to 9.09 inches, occurred during the year 1898, the year of maximum annual temperature. The mean temperature during the replenishing period in 1898 was 46.2 degrees Fahrenheit, or only 0.1 of a degree less than the maximum value. The maximum temperature occurred in 1901. The minimum rainfall, 3.16 inches and

the minimum retention, 2.25 inches, both occurred in 1909. The minimum runoff, 0.56 inches occurred in 1902, when the total annual runoff was only 0.1 of an inch greater than the minimum annual amount. The minimum temperature for this period, 36.6 degrees, occurred in 1918, calendar year 1917, the early part of the unusually severe winter of 1917 and 1918. It is interesting to note that the minimum ratio of runoff to rainfall, for this period, occurred in the year 1896, immediately following the growing period in which the rainfall, runoff, and retention were all minimum values; also that the maximum value of this ratio occurred in 1897, immediately following the growing period in which the rainfall and retention were maximum values. The ratio was unusually low in 1896 because the necessary replenishing of the soil storage was considerably greater than usual. It was unusually high in 1897 because the replenishing had been accomplished to an extent greater than usual during the preceding period, thus causing a relatively high ground water flow.

Storage Period

The maximum values of rainfall and runoff during the storage period, 23.88 and 20.89 inches respectively, both occurred in 1913, the year of maximum annual runoff and minimum annual evaporation. These maxima were undoubtedly caused primarily by the great storm and resulting disastrous flood of March 23 to 27. The minimum rainfall, 6.21 inches, the minimum runoff, 1.38 inches, and the minimum ratio of runoff to rainfall, 22.2 per cent, all occurred in 1902, the year in which the ratio of annual runoff to annual rainfall was a minimum and in which the annual runoff was only 0.1 of an inch greater than the minimum value. The maximum retention, 8.99 inches, occurred in 1909. The minimum retention occurred in 1912, the runoff during this period being greater than the rainfall. This record, however, is probably uncertain due to errors in the runoff. As explained in the discussion of the records at Hamilton the runoff records for Dayton for 1912 are believed to be somewhat too high. The retention during the storage period was probably a minimum in 1910, when the record amounted to 0.48 of an inch. The maximum ratio of runoff to rainfall given as 100.7 in 1912 is also undoubtedly in error due to the error in runoff records. The value of 87.5 per cent given for the years 1913 and 1916 probably represents the maximum value for this period. The min-

imum temperature, 32.8 degrees, occurred in 1912; and the maximum, 41.8 degrees, occurred in 1894.

Growing Period

During the growing season the minimum rainfall, minimum runoff, and minimum retention all occurred in the year 1895, the year of minimum annual rainfall. The maximum rainfall and maximum retention occurred the following year, the year of maximum annual rainfall and maximum annual evaporation. The maximum runoff for this period occurred in 1915, and was probably due to the floods of July of that year. The minimum ratio of runoff to rainfall occurred in 1902, the year in which the minimum ratio for the storage period occurred, and in which the total annual runoff was only 0.1 of an inch greater than the minimum annual amount. The maximum value of this ratio occurred in 1909 when the runoff and rainfall were both considerably above normal. The maximum temperature occurred in 1900. The minimum temperature occurred in 1917 preceding the unusually severe winter of 1917 and 1918.

MONTHLY RAINFALL AND RUNOFF

Tables 25 to 28, inclusive, give the monthly rainfall, runoff, retention, and ratio of runoff to rainfall, for the drainage area of the Miami River above Dayton. Table 29 gives the monthly temperatures at Dayton. Maximum and minimum records are indicated as in the preceding tables; and the average values of the various quantities are included. Ratios of the maximum records to the mean and minimum records are given for the rainfall, runoff, retention, and temperature.

Figure 33 shows the maximum, mean, and minimum values of the various quantities. The maximum values are platted together in the upper part of the figure, the mean values near the center, and the minimum values in the lower part. It should be noted that since the maximum and minimum values of the rainfall, runoff, and retention frequently occur in different years, the relation that the retention is equal to the rainfall minus the runoff holds only for the mean curves. Only the mean values of the ratio of runoff to rainfall are platted. The maximum and minimum values are so erratic, due to the short periods of time considered, that they are practically meaningless. Figure 34 shows the same data as figure 33, arranged somewhat differently.

Table 25.—Average Monthly Rainfall on Drainage Area above Dayton for years Ending September 30, 1894 to 1918, inclusive, in Inches

Year Ending September 30	October	November	December	January	February	March	April	May	June	July	August	September	Total for Year
1894	3.62	2.10	2.28	1.76	3.51	2.36	1.99	4.07	2.38	**1.12**	2.42	3.06	30.67
1895	2.12	2.54	2.66	3.65	0.59	1.36	2.00	1.81	3.02	1.28	2.03	0.97	**24.03**
1896	0.99	5.44	3.44	1.70	1.76	3.44	2.06	3.37	3.92	**8.94**	5.06	**6.13**	**46.25**
1897	0.75	2.44	1.70	1.93	2.21	6.16	3.73	3.94	3.54	3.90	2.30	0.68	33.28
1898	0.79	**7.63**	2.32	4.98	1.99	7.87	2.24	4.28	2.62	3.14	3.55	2.87	44.28
1899	4.00	3.60	2.69	3.42	1.94	4.26	**1.25**	2.97	**1.83**	4.50	2.05	1.66	34.17
1900	2.28	1.81	3.17	2.74	3.69	2.29	1.99	3.30	3.98	3.95	3.81	2.12	35.13
1901	2.48	3.76	1.25	2.06	1.30	2.85	2.09	3.12	4.09	2.26	2.92	1.93	30.11
1902	1.16	0.96	3.60	**1.00**	0.65	2.82	1.74	2.45	**7.92**	3.01	1.64	4.66	31.61
1903	2.69	3.04	3.62	2.26	4.36	3.01	3.63	3.78	4.93	2.62	1.90	1.29	37.13
1904	2.68	2.15	2.08	4.19	2.50	7.70	4.00	3.22	3.31	3.00	2.22	2.07	39.12
1905	1.47	**0.25**	3.89	1.61	1.62	2.04	3.87	5.52	4.25	2.85	**6.00**	5.11	38.48
1906	3.83	1.90	2.09	2.09	0.94	4.47	1.70	2.34	2.40	4.50	4.88	2.03	33.17
1907	2.06	3.14	3.29	6.88	**0.40**	4.89	2.39	2.97	5.08	6.00	2.60	3.38	43.08
1908	2.34	2.26	3.40	1.51	4.52	5.89	3.55	4.55	3.05	4.13	2.05	**0.41**	37.66
1909	**0.56**	0.94	1.66	2.57	**5.76**	2.38	**4.62**	**5.72**	5.75	4.70	3.26	1.39	39.31
1910	3.61	2.72	2.73	3.62	3.93	**0.07**	3.08	4.00	2.10	3.56	**1.30**	5.54	36.26
1911	**6.27**	1.75	2.16	3.75	1.48	2.23	4.52	**1.80**	3.54	2.15	5.31	4.89	39.85
1912	5.02	2.92	3.49	2.14	2.27	4.81	4.49	3.35	2.86	5.16	4.30	3.03	43.84
1913	2.38	1.00	1.80	**7.33**	1.64	**10.51**	4.40	3.04	2.23	4.00	2.51	2.04	42.88
1914	2.92	3.43	**0.90**	2.40	3.08	2.25	3.54	2.19	2.66	2.63	4.88	1.28	32.16
1915	3.37	1.39	3.19	3.18	1.46	1.37	1.73	4.50	4.06	7.00	5.40	4.57	41.22
1916	2.35	2.40	**3.98**	6.20	1.26	3.73	2.57	4.33	5.26	1.41	2.92	3.14	39.55
1917	1.59	1.76	2.72	3.81	1.27	3.71	3.66	4.32	5.14	4.04	2.32	1.91	36.25
1918	4.01	0.31	1.21	3.46	1.86	2.55	3.67	4.48	3.42	3.44	4.42	4.06	36.89
Average	2.61	2.47	2.61	3.21	2.24	3.80	2.98	3.58	3.73	3.73	3.28	2.81	37.07
Max. ÷ Ave.	2.40	3.09	1.52	2.28	2.57	2.76	1.55	1.60	2.12	2.40	1.83	2.18	1.25
Max. ÷ Min.	11.2	30.5	4.42	7.33	14.4	150.	3.70	3.18	4.33	7.98	4.61	14.9	1.92

Table 26.—Monthly Runoff from Drainage Area above Dayton, in Inches, for Years Ending September 30, 1894 to 1918

Year Ending September 30	October	November	December	January	February	March	April	May	June	July	August	September	Total for Year
1894	.25	.24	.33	.33	1.11	.80	.43	.41	.32	.26	.22	.22	4.92
1895	.22	.24	.30	.70	**.25**	.57	**.36**	.26	**.24**	**.21**	.18	**.19**	**3.72**
1896	**.16**	.24	.47	.68	.74	1.03	.59	.40	.44	1.46	**1.15**	.71	8.08
1897	1.27	.57	.73	.61	1.55	3.56	1.48	1.10	.57	.70	.36	.28	12.78
1898	.21	.82	.62	2.94	.98	5.25	1.06	1.11	.50	.42	.43	.36	14.70
1899	.47	.78	1.12	2.30	.94	1.72	.74	.50	.34	.32	.25	.23	9.72
1900	.21	.22	.36	.86	.93	1.47	.65	.37	.51	.32	.47	.21	6.58
1901	.35	.42	.38	.51	.44	1.26	.62	.48	.51	.30	.20	**.18**	5.65
1902	**.16**	**.14**	**.26**	.24	.25	**.49**	.40	**.24**	.48	.67	.24	**.18**	3.76
1903	.64	.48	1.46	1.40	2.30	3.06	1.13	.56	.80	.31	.23	.20	12.56
1904	.23	.26	.37	1.94	2.21	3.74	2.31	.48	.51	.68	.20	**.18**	13.09
1905	.17	.16	**.26**	.26	.45	.83	.67	1.82	.64	.29	.56	.99	7.08
1906	.54	.52	.72	1.41	.58	2.16	1.44	.38	.26	.45	.48	.21	9.18
1907	.25	.78	.97	5.21	.94	3.28	.76	.64	**1.95**	1.40	.44	.50	17.15
1908	.48	.52	1.12	1.28	3.36	5.74	1.50	2.14	.57	.44	.38	.19	17.72
1909	.19	.23	.49	.64	2.62	1.66	1.42	**3.11**	1.00	.89	.56	.27	13.12
1910	.49	.76	1.42	4.66	2.41	2.59	.56	.75	.35	.42	.20	.51	15.13
1911	**2.94**	.44	.81	2.90	1.44	.86	1.86	1.11	.36	.29	.33	.58	13.91
1912	1.86	**1.47**	**2.30**	2.26	**3.46**	5.13	2.96	1.10	.72	.94	.51	.37	23.09
1913	.31	.29	.29	5.27	.94	**10.51**	**4.17**	1.09	.69	.37	.21	.22	**24.36**
1914	.23	.31	.28	.33	1.07	2.18	2.35	.68	.24	**.21**	.21	.22	8.33
1915	.34	.19	.41	.87	3.10	.66	.43	.40	.86	**2.68**	1.04	**1.12**	12.08
1916	1.01	.76	1.31	**5.28**	2.37	2.97	1.43	1.85	1.36	.36	.27	.29	19.25
1917	.23	.20	.41	1.79	1.24	2.32	1.20	1.14	1.02	1.40	.30	.20	11.43
1918	.29	.33	.31	.78	2.75	1.60	.58	1.24	.33	.31	.31	.60	9.42
Average	0.54	0.45	0.70	1.82	1.54	2.62	1.24	0.93	0.62	0.64	0.39	0.37	11.87
Max.÷Ave.	5.44	3.27	3.28	2.90	2.25	4.01	3.36	3.34	3.15	4.19	2.95	3.03	2.05
Max.÷Min.	18.4	10.5	8.84	22.0	13.8	21.5	11.6	12.9	8.13	12 7	6.40	6.22	6.60

Table 27.—Monthly Retention on Drainage Area Above Dayton for Years Ending September 30, 1894 to 1918, inclusive, in Inches

Year Ending September 30	October	November	December	January	February	March	April	May	June	July	August	September
1894	3.37	1.86	1.95	1.43	2.40	1.56	1.56	3.66	2.06	.86	2.20	2.84
1895	1.90	2.30	2.36	2.95	.34	.79	1.64	1.55	2.78	1.07	1.85	.78
1896	.83	5.20	2.97	1.02	1.02	2.41	1.47	2.97	3.48	7.48	3.91	5.42
1897	—.52	1.87	.97	1.32	.66	2.60	2.25	2.84	2.97	3.20	1.94	.40
1898	.58	6.81	1.70	2.04	1.01	2.62	1.18	3.17	2.12	2.72	3.12	2.51
1899	3.53	2.82	1.57	1.12	1.00	2.54	.51	2.47	1.49	4.18	1.80	1.43
1900	2.07	1.59	2.81	1.88	2.76	.82	1.34	2.93	3.47	3.63	3.34	1.91
1901	2.13	3.34	.87	1.55	.86	1.59	1.47	2.64	3.58	1.96	2.72	1.75
1902	1.00	0.82	3.34	.76	.40	2.33	1.34	2.21	7.44	2.34	1.40	4.48
1903	2.05	2.56	2.16	.86	2.06	—.05	2.50	3.22	4.13	2.31	1.67	1.09
1904	2.45	1.89	1.71	2.25	.29	3.96	1.69	2.74	2.80	2.32	2.02	1.89
1905	1.30	.09	3.63	1.35	1.17	1.21	3.20	3.70	3.61	2.56	5.44	4.12
1906	3.29	1.38	1.37	.68	.36	2.31	.26	1.96	2.14	4.05	4.40	1.82
1907	1.81	2.36	2.32	1.67	—.54	1.61	1.63	2.33	3.13	4.60	2.16	2.88
1908	1.86	1.74	2.28	.23	1.16	.15	2.05	2.41	2.48	3.69	1.67	.22
1909	.37	.71	1.17	1.93	3.14	.72	3.20	2.61	4.75	3.81	2.70	1.12
1910	3.12	1.96	1.31	—1.04	1.52	—2.52	2.52	3.25	1.75	3.14	1.10	5.03
1911	3.33	1.31	1.35	.85	.04	1.37	2.66	.69	3.18	1.86	4.98	4.31
1912	3.16	1.45	1.19	—.12	—1.19	—.32	1.53	2.25	2.14	4.22	3.79	2.66
1913	2.07	.71	1.51	2.06	.70	0	.23	1.95	1.54	3.63	2.30	1.82
1914	2.69	3.12	.62	2.07	2.01	.07	1.19	1.51	2.42	2.42	4.67	1.06
1915	3.03	1.20	2.78	2.31	—1.64	.71	1.30	4.10	3.20	4.32	4.36	3.45
1916	1.34	1.64	2.67	.92	—1.12	.76	1.14	2.48	3.90	1.05	2.65	2.85
1917	1.36	1.56	2.31	2.02	.03	1.39	2.46	3.18	4.12	2.64	2.02	1.71
1918	3.72	—.02	.90	2.68	—.89	.95	3.09	3.24	3.09	3.13	4.11	3.46
Average*	2.07	2.02	1.91	1.39	.70	1.18	1.74	2.65	3.11	3.09	2.89	2.44
Max.÷Ave.	1.80	3.37	1.90	2.12	4.48	3.35	1.84	1.55	2.39	2.42	1.88	2.22
Max.÷Min.	......	......	5.86	......	......	......	13.9	5.94	4.99	8.70	4.94	24.6

*Computed from average values of monthly rainfall and runoff.

Table 28.—Ratio of Monthly Runoff to Monthly Rainfall on Drain age Area Above Dayton for Years Ending September 30, 1894, to 1918, inclusive, in Per Cent

Year Ending September 30	October	November	December	January	February	March	April	May	June	July	August	September
1894	6.9	11.4	14.5	18.8	31.6	33.9	21.6	10.1	13.4	23.2	9.1	7.2
1895	10.4	9.4	11.3	19.2	42.4	41.9	18.0	14.4	8.0	16.4	8.9	19.6
1896	16.2	4.4	13.7	40.0	42.0	30.0	28.6	11.9	11.2	16.3	22.7	11.6
1897	169.5	23.4	42.9	31.6	70.2	57.8	39.7	27.9	16.1	18.0	15.6	41.1
1898	26.6	10.8	26.7	59.0	49.2	66.8	47.3	25.9	19.1	13.4	12.1	12.6
1899	11.7	21.7	41.7	67.2	48.5	40.4	59.2	16.9	18.6	7.1	12.2	13.9
1900	9.2	12.2	11.4	31.4	25.2	64.2	32.7	11.2	12.8	8.1	12.3	9.9
1901	14.1	11.2	30.4	24.7	33.8	44.2	29.7	15.4	12.5	13.3	6.8	9.3
1902	13.8	14.6	7.2	24.0	38.5	17.4	23.0	9.8	6.1	22.3	14.6	3.9
1903	23.8	15.8	40.3	62.0	52.8	101.6	31.1	14.8	16.2	11.8	12.1	15.5
1904	8.6	12.1	17.8	46.3	88.4	48.6	57.8	14.9	15.4	22.7	9.0	8.7
1905	11.6	64.0	6.7	16.2	27.8	40.7	17.3	32.8	15.1	10.2	9.3	19.4
1906	14.1	27.4	34.5	67.5	61.7	48.3	84.7	16.2	10.8	10.0	9.8	10.3
1907	12.1	24.8	29.5	75.8	235.0	67.1	31.8	21.6	38.4	23.3	16.9	14.8
1908	20.5	23.0	32.9	84.8	74.4	97.5	42.3	47.1	18.7	10.6	18.5	46.3
1909	33.9	24.5	29.5	24.9	45.5	69.8	30.7	54.4	17.4	19.0	17.2	19.4
1910	13.6	28.0	52.0	128.8	61.4	3700.0	18.2	18.8	16.7	11.8	15.4	9.2
1911	46.9	25.2	37.5	77.3	97.3	38.6	41.2	61.6	10.2	13.5	6.2	11.9
1912	37.0	50.4	65.9	105.6	152.5	106.6	66.0	32.8	25.2	18.2	11.9	12.2
1913	13.0	29.0	16.1	71.9	57.3	100.0	94.8	35.9	30.9	9.2	8.4	10.8
1914	7.9	9.0	31.1	13.8	34.7	97.0	66.4	31.1	9.0	8.0	4.3	17.2
1915	10.1	13.7	12.9	27.4	212.2	48.2	24.8	8.9	21.2	38.3	19.3	24.4
1916	42.9	31.7	32.9	85.2	188.0	79.6	55.6	42.7	25.9	25.5	9.2	9.2
1917	14.5	11.4	15.1	47.0	97.6	62.6	32.8	26.4	19.8	34.7	12.9	10.5
1918	7.2	106.2	25.6	22.5	147.8	62.8	15.8	27.7	9.6	9.0	7.0	14.8
Average†	20.7	18.4	26.8	56.6	68.7	68.8	41.7	26.1	16.7	17.2	11.8	13.1

†Computed from average values of runoff and rainfall given in preceding tables.

Table 29.—Mean Monthly Temperature at Dayton, in Degrees F.

Year Ending September 30	October	November	December	January	February	March	April	May	June	July	August	September	Total for Year
1893	54.2	38.3	31.3	21.7	32.3	42.7	52.7	61.6	72.6	78.2	72.5	67.8	52.1
1894	54.4	40.9	35.3	35.8	30.7	47.4	53.3	62.5	74.4	76.7	74.3	70.3	54.7
1895	51.0	40.7	34.2	†29.6	†30.7	33.8	53.9	63.5	**75.1**	73.7	76.5	72.2	53.0
1896	48.8	42.6	37.0	32.0	33.8	35.6	**60.0**	**71.2**	72.0	76.5	74.4	64.4	54.0
1897	51.0	46.8	36.2	27.7	35.2	44.8	51.0	58.4	71.1	78.5	71.9	69.0	53.4
1898	60.4	44.2	34.0	34.0	33.0	47.1	49.4	64.0	75.4	74.2	75.2	70.6	**55.0**
1899	56.4	40.9	29.6	31.2	23.2	39.5	56.9	66.4	74.2	76.0	76.6	67.2	53.2
1900	59.4	45.7	31.2	33.8	28.5	35.6	52.4	65.2	72.4	76.4	**79.2**	**72.8**	54.4
1901	**63.0**	43.0	33.0	30.2	24.4	41.9	48.0	60.4	73.8	**80.6**	75.8	66.7	53.4
1902	54.8	38.4	28.0	28.9	22.2	43.0	50.2	65.4	69.8	75.8	71.9	65.4	51.1
1903	56.6	49.8	30.9	28.1	31.9	47.6	51.0	65.2	**65.7**	75.2	74.3	67.4	53.6
1904	55.6	38.2	25.8	21.3	25.3	42.2	45.4	61.6	70.2	73.6	71.6	66.6	**49.8**
1905	53.6	41.8	29.3	24.4	**22.1**	45.8	51.2	62.3	71.8	74.8	74.0	66.8	51.5
1906	53.8	41.2	33.6	36.0	28.4	**32.3**	53.8	63.2	71.3	74.0	76.6	70.8	52.9
1907	53.8	41.9	33.5	34.7	29.0	49.4	42.8	56.2	67.9	75.0	71.6	67.2	51.9
1908	50.6	39.8	34.3	31.0	30.2	44.8	52.2	64.2	70.8	75.8	73.8	69.2	53.1
1909	54.9	43.3	35.2	33.0	**37.7**	39.8	50.7	50.3	72.6	* 72.2	74.4	64.3	53.2
1910	50.0	**51.0**	26.4	29.7	27.0	**50.4**	52.6	57.2	68.2	75.0	73.0	67.7	52.3
1911	57.6	**37.6**	27.4	35.1	36.8	40.0	49.3	67.6	72.9	76.4	74.4	70.0	53.7
1912	54.6	37.7	**37.4**	19.0	23.6	34.0	54.4	64.7	68.9	75.4	71.6	68.4	50.8
1913	55.2	43.4	35.2	**37.6**	28.8	42.0	51.0	62.6	72.2	77.2	76.0	66.4	54.0
1914	54.9	46.3	35.5	34.8	23.9	37.6	51.3	63.6	73.9	77.0	74.5	66.0	53.3
1915	58.4	43.8	28.2	27.2	37.6	34.6	56.8	59.8	68.6	73.4	**68.3**	68.4	52.1
1916	56.6	45.9	32.1	37.0	28.4	37.4	50.6	63.8	66.2	79.7	75.9	65.0	53.2
1917	53.8	44.2	30.8	30.6	28.4	41.9	50.4	**55.3**	68.3	73.5	72.6	63.2	51.1
1918	48.2	40.0	**21.7**	**15.7**	33.0	46.4	50.0	68.2	70.8	72.3	78.2	**59.2**	50.3
Average	54.7	42.6	31.8	30.0	29.5	41.4	51.6	62.9	71.1	75.7	74.2	67.4	52.7
Max.÷Ave.	1.15	1.20	1.18	1.25	1.28	1.22	1.16	1.13	1.06	1.06	1.07	1.08	1.04
Max.÷Min.	1.31	1.36	1.72	2.39	1.71	1.56	1.40	1.29	1.14	1.12	1.16	1.23	1.10

†Normal values; records missing.
*Preceding data copied from cooperative station records in the local office of the U. S. Weather Bureau. Following data copied from U. S. Monthly Weather Review and Climatological data.

In this case the three temperature curves are kept together, the three rainfall curves together, and so on.

The mean distribution of the rainfall, runoff, retention, and temperature throughout the year is shown by the group of curves in the center of figure 33, as well as by the average values given at the bottom of the tables. The minimum mean monthly rainfall occurs during the month of February and amounts to 2.24 inches. If the record were increased so as to correspond to a month of 30 days instead of 28 the amount would still be less than the record for November, the next lowest month. March seems to be the month of heaviest rainfall, the average for this month being 3.80 inches. However, the value of 3.73 inches obtained for the months of June and July is practically as great. There appears to be a decrease in rainfall during April, the average amount for this month being only 2.98 inches. It is interesting to note that a similar decrease during this month is shown by the majority of the diagrams for southwestern Ohio, published by the U. S. Weather Bureau, in Volume II of Bulletin W.* The rainfall is generally low during the months of October, November, and December; and generally high during the months of May, June, and July.

The distribution of runoff during the year is slightly different from the rainfall distribution, inasmuch as it is generally low during the summer months. However, the month of greatest runoff is the same as the month of greatest rainfall, the monthly runoff being a maximum during March, amounting to 2.62 inches. September is the month of lowest runoff, the average for this month being only 0.37 inches.

The curve of mean retention follows, in a way, the curve of mean temperature, being high in the summer and low in the winter. The minimum monthly retention occurs in February, the month of minimum rainfall, and amounts to only 0.70 inches. June is the month of maximum retention, the average for this month being 3.11 inches.

The curve of the average ratio of runoff to rainfall is just the reverse of the temperature curve, being high in the winter and low in the summer. The maximum ratio of monthly runoff to monthly rainfall occurs in March, being 68.8 per cent. The minimum ratio occurs in August, being 11.8 per cent.

A study of the maximum and minimum values, and of the ratios given at the bottom of the tables, shows that the various

*Summary of Climatological Data East of the Mississippi River, Bulletin W, Volume II, U. S. Weather Bureau, Washington, D. C., 1912.

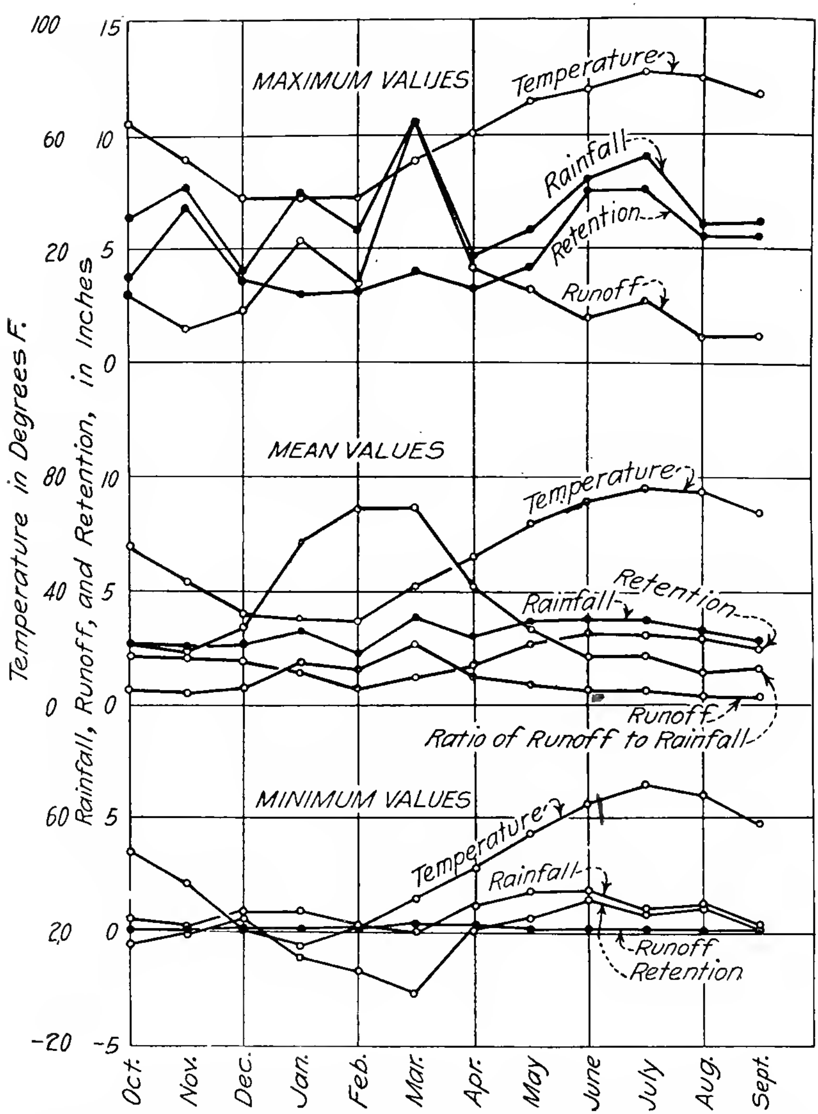

FIG. 33.—MAXIMUM, MEAN, AND MINIMUM MONTHLY RAINFALL, RUNOFF, RETENTION, AND TEMPERATURE ABOVE DAYTON.

The ratio of the mean monthly runoff to the mean monthly rainfall, expressed as a percentage, has been added to the group of mean values.

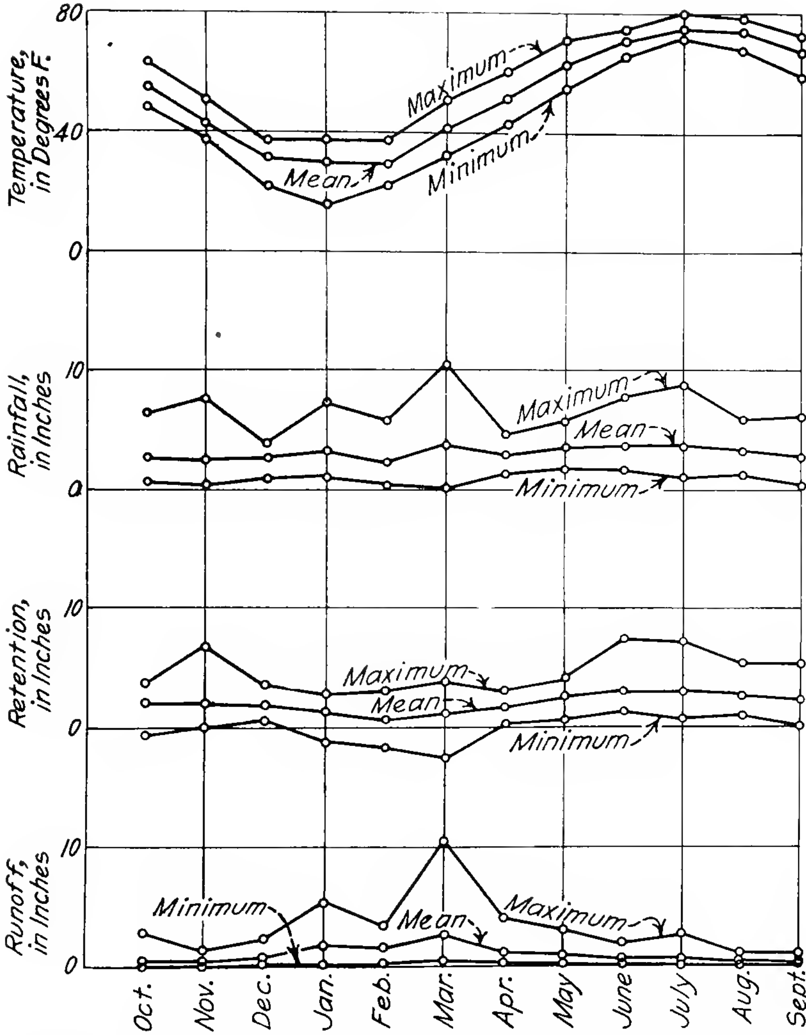

FIG. 34.—MAXIMUM, MEAN, AND MINIMUM MONTHLY RAINFALL, RUNOFF, RETENTION, AND TEMPERATURE ABOVE DAYTON.

Curves shown in figure 33 have been arranged so as to show more clearly the differences between the maximum and the minimum values of the various quantities.

quantities are all quite variable, much more variable than the annual or seasonal quantities, as would naturally be expected. The runoff again seems to be considerably more variable than either the rainfall or the retention.

The maximum rainfall during any one month of the entire record occurred in March, 1913, due to the great storm of March 24 to 27, and amounted to 10.51 inches. The maximum runoff for any one month also occurred during March, 1913, and amounted to the same value. The ground water flow at this time was unusually high due to the heavy precipitation of the preceding January. The minimum rainfall for the entire period occurred in March, 1910, and amounted to only 0.07 of an inch. The minimum runoff occurred in November, 1902, calendar year 1901, amounting to only 0.14 of an inch.

Maximum and minimum values of monthly retention and ratio of runoff to rainfall, as well as all individual values, are more or less erratic due to the short period of time considered. The runoff very frequently is not comparable with the rainfall for the same month. Probably the chief value of the data given in tables 27 and 28 is to show this. During the winter months the runoff is often greater than the precipitation, due either to snow accumulations or to floods in the early part of the month caused by heavy precipitation during the late part of the preceding month. The runoff during February, 1916, was greater than the rainfall, due to the flood runoff resulting from the heavy precipitation of January 30 and 31. The runoff of February, 1918, was greater than the rainfall, due to the melting of the heavy snows which had fallen during January. Other negative values of retention might be similarly explained.

The curves of maximum, mean, and minimum monthly temperature given in figure 34 need no discussion. However, it is interesting to note that the minimum records for October, December, and January all occurred during the unusually severe winter of 1917 and 1918.

SURFACE AND GROUND WATER FLOW

Table 30 shows the relation between surface and ground water flow for the drainage areas of the Miami River above Dayton, of Mad River above Wright, of Buck Creek above Springfield, and of Stillwater River above West Milton. The annual amounts of surface runoff and of ground water runoff are given in inches depth over the drainage areas and in percentages of the total

runoff, for each year for which records are available. The total annual runoff in inches is also included. The maximum and minimum records are indicated as before.

The proportions of annual runoff which appear as surface or flood flow and as low water or ground water flow can be determined only approximately. No exact separation is possible. In calculating the data given in table 30, the separation was made on the hydrographs in the following manner: Lines representing the rate of ground water flow were drawn so as to pass through the low points only, as shown in figures 35 to 39, inclusive. The endeavor was to draw the lines so that the increased flow of tiles immediately after a flood, that is, the drainage of the surface soil, would be included in the surface or flood runoff rather than in the ground water runoff, since such flow acts more nearly like surface flow than like low water flow. It was also assumed that no percolation occurs during the growing season or before the latter part of the replenishing period, that is, during the period from about May 1 to about December 1. Having arbitrarily drawn the curve representing the rate of ground water flow, it was, of course, simply a matter of calculation to determine the total amounts of surface and ground water runoff during the year.

Reference to table 30 shows that in the Miami Valley above Dayton the surface flow is about two-thirds of the total runoff, and the ground water flow about one-third. In the Buck Creek Valley the surface flow contributes only about 44 per cent of the total and the ground water flow about 56 per cent. In the Mad River Valley above Wright, including the Buck Creek Valley, the surface flow amounts to about 53 per cent of the total and the ground water flow, to about 47 per cent. In the Stillwater River Valley the surface flow constitutes about 79 per cent of the total and the ground water flow, only about 21 per cent.

These wide differences in the proportions of surface and ground water flow are the result of variations in geological and soil conditions. In the Mad River Valley there is relatively large underground storage in deep deposits of glacial gravel, while the comparatively loose and shallow surface soil permits rapid percolation. Gravel deposits are less extensive in the Miami Valley above Dayton, and still less frequent in the Stillwater Valley. Over a considerable portion of the latter basin there are but a few feet of residual clay soil overlying the bed rock, which generally is limestone. On these drainage areas surface slope

Table 30.—Surface and Ground Water Runoff in the Miami Valley

Year Ending September 30	Total Runoff in Inches	Surface Runoff		Ground Water Runoff	
		Inches	% of Total	Inches	% of Total
DRAINAGE AREA OF THE MIAMI RIVER ABOVE DAYTON					
1894	4.92	1.90	38.6	3.02	61.4
1895	3.72	1.29	34.7	2.43	65.3
1896	8.08	4.47	55.3	3.61	44.7
1897	12.78	8.19	64.1	4.59	35.9
1898	14.70	10.41	70.8	4.29	29.2
1899	9.72	5.32	54.7	4.40	45.3
1900	6.58	3.16	48.0	3.42	52.0
1901	5.65	2.67	47.3	2.98	52.7
1902	3.76	1.56	41.5	2.20	58.5
1903	12.56	7.77	61.9	4.79	38.1
1904	13.09	9.38	71.7	3.71	28.3
1905	7.08	4.46	63.0	2.62	37.0
1906	9.18	5.25	57.2	3.93	42.8
1907	17.16	11.38	66.3	5.78	33.7
1908	17.72	12.52	70.7	5.20	29.3
1909	13.12	8.31	63.3	4.81	36.7
1910	15.13	10.56	69.8	4.57	30.2
1911	13.91	9.18	66.0	4.73	34.0
1912	23.09	16.18	70.1	6.91	29.9
1913	24.36	19.71	80.9	4.65	19.1
1914	8.33	4.95	59.4	3.38	40.6
1915	12.09	8.58	71.0	3.51	29.0
1916	19.25	14.19	73.7	5.06	26.3
1917	11.43	7.41	64.8	4.02	35.2
1918	9.42	6.44	68.4	2.98	31.6
1919	11.15	6.71	60.2	4.44	39.8
Average	11.85	7.77	65.6	4.08	34.4
DRAINAGE AREA OF BUCK CREEK ABOVE SPRINGFIELD					
1915	8.34	3.92	47.0	4.42	53.0
1916	14.75	6.73	45.6	8.02	54.4
1917	10.25	4.77	46.5	5.48	53.5
1918	10.10	4.64	45.9	5.46	54.1
1919	11.04	4.10	37.1	6.94	62.9
Average	10.89	4.83	44.3	6.06	55.7
DRAINAGE AREA OF MAD RIVER ABOVE WRIGHT					
1915	12.03	6.86	57.0	5.17	43.0
1916	19.39	11.85	61.1	7.54	38.9
1917	13.48	6.75	50.1	6.73	49.9
1918	11.09	5.69	51.3	5.40	48.7
1919	12.89	5.56	43.1	7.33	56.9
Average	13.78	7.34	53.3	6.44	46.7
DRAINAGE AREA OF STILLWATER RIVER ABOVE WEST MILTON					
1915	12.63	10.63	84.2	2.00	15.8
1916	17.63	14.30	81.1	3.33	18.9
1917	12.33	8.73	70.8	3.60	29.2
1918	13.30	10.34	77.7	2.96	22.3
1919	12.00	9.48	79.0	2.52	21.0
Average	13.58	10.70	78.8	2.88	21.2

has but little influence on runoff. In fact the surface slopes are steeper over the Mad River drainage area where percolation is great, than on the Stillwater where flood runoff predominates.

Considering the Dayton records the surface flow is seen to vary from only 1.29 inches in 1895, the year of minimum annual runoff, to 19.71 inches in 1913, the year of maximum annual runoff. The percentages of the totals for these years were 34.7 and 80.9 respectively, which are the minimum and maximum percentages. The ground water flow varied from 2.20 inches in 1902, the year in which the rainfall during the storage period, when practically all of the percolation occurs, was a minimum, to 6.91 inches in 1912. However, as previously mentioned, the record for the year 1912 is believed to be too high. Probably the value of 5.78 inches given for the year 1907 represents the true maximum amount. The ground water flow was a maximum percentage of the total in 1895, the year of minimum surface and minimum total runoff; and a minimum percentage of the total in 1913, the year of maximum surface and maximum total runoff.

The minimum and maximum values for the other drainage areas are, of course, very uncertain due to the shortness of the record. However, a study of the averages of the Dayton records for the years 1915 to 1919 inclusive, and of those for the entire period of record, indicates that the averages for the other drainage areas are not greatly in error.

The annual ground water runoff is much less variable than the annual surface flow, as would be expected. The maximum value of the annual surface runoff in the Miami Valley above Dayton, 19.71 inches, is about 15.3 times the minimum value, while the maximum value of the ground water runoff, using the 1912 record, is only about 3.14 times the minimum value.

MASS CURVES

The hydrology of a drainage area may be shown conveniently by means of mass curves. Such curves have been drawn for the Mad River Valley above Wright for the years 1915 to 1919, inclusive. They are shown in figures 35 to 39, one year's records being shown in each figure. Separate curves have been drawn to show the rainfall, ground water runoff, flood runoff, total runoff, retention, soil absorption, percolation, and evaporation. In order to avoid confusion the rainfall curve was arbitrarily started at 10 inches on the scale instead of at 0. Hydrographs showing the rate of discharge and the arbitrary separation of

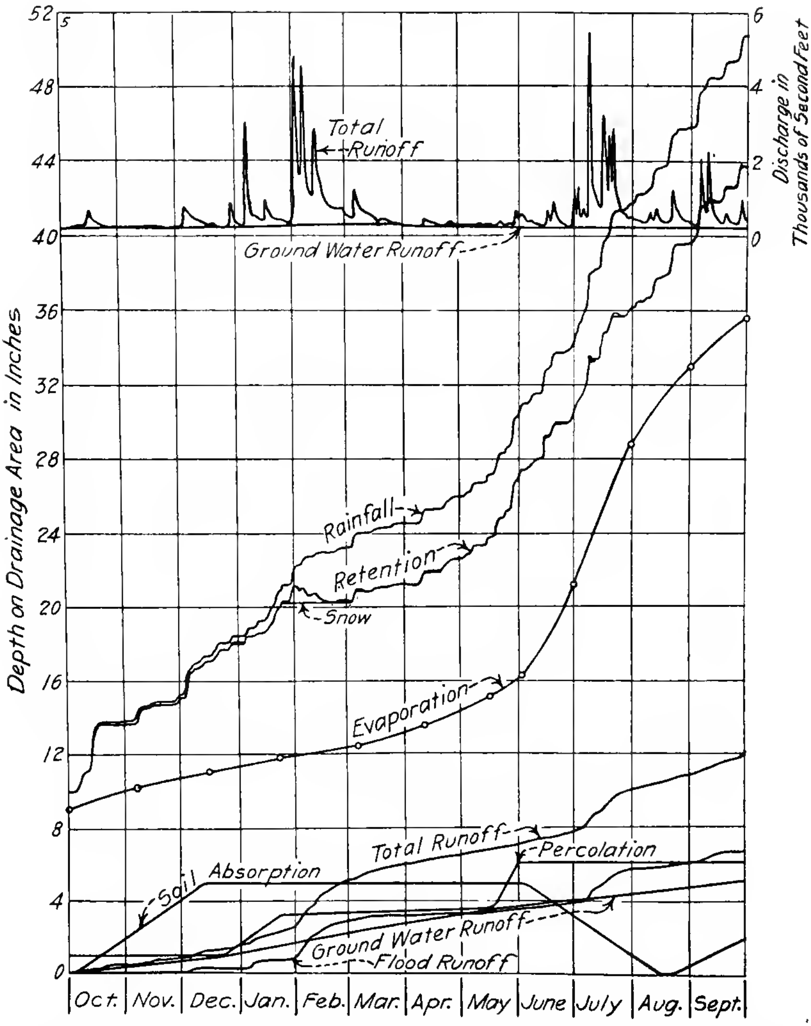

FIG. 35.—HYDROLOGY OF THE MAD RIVER VALLEY ABOVE WRIGHT DURING 1915

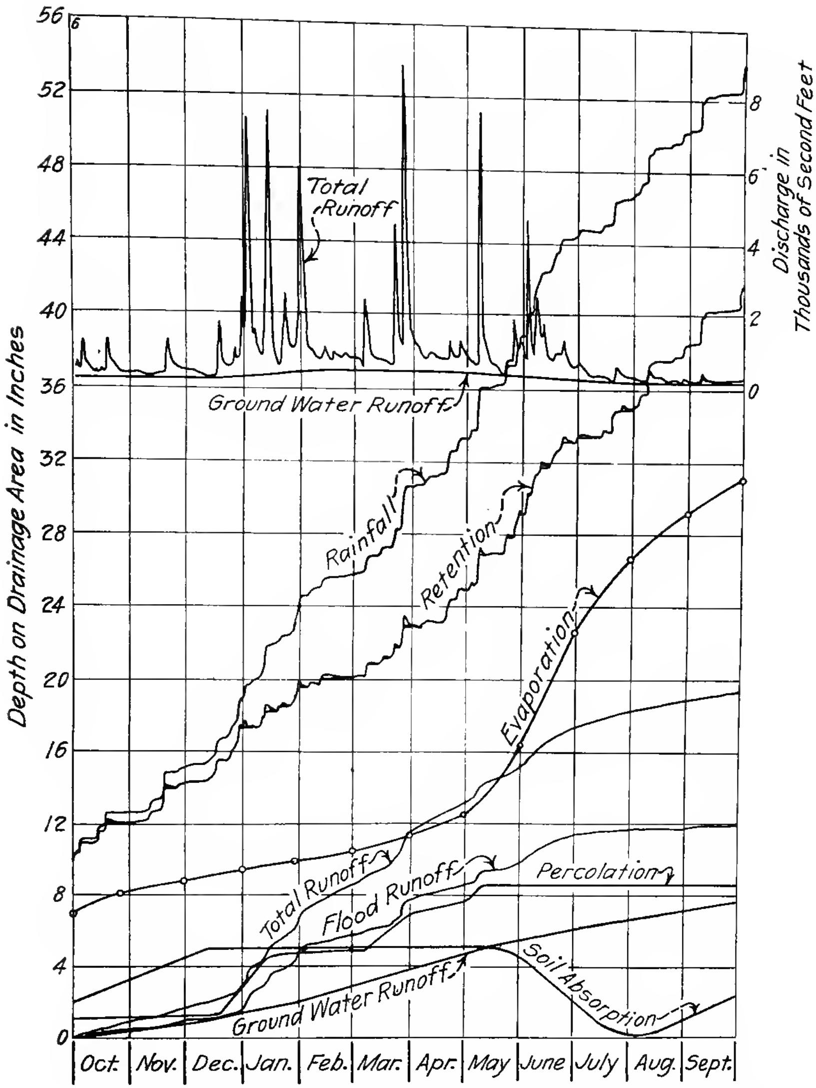

FIG. 36.—HYDROLOGY OF THE MAD RIVER VALLEY ABOVE WRIGHT DURING 1916.

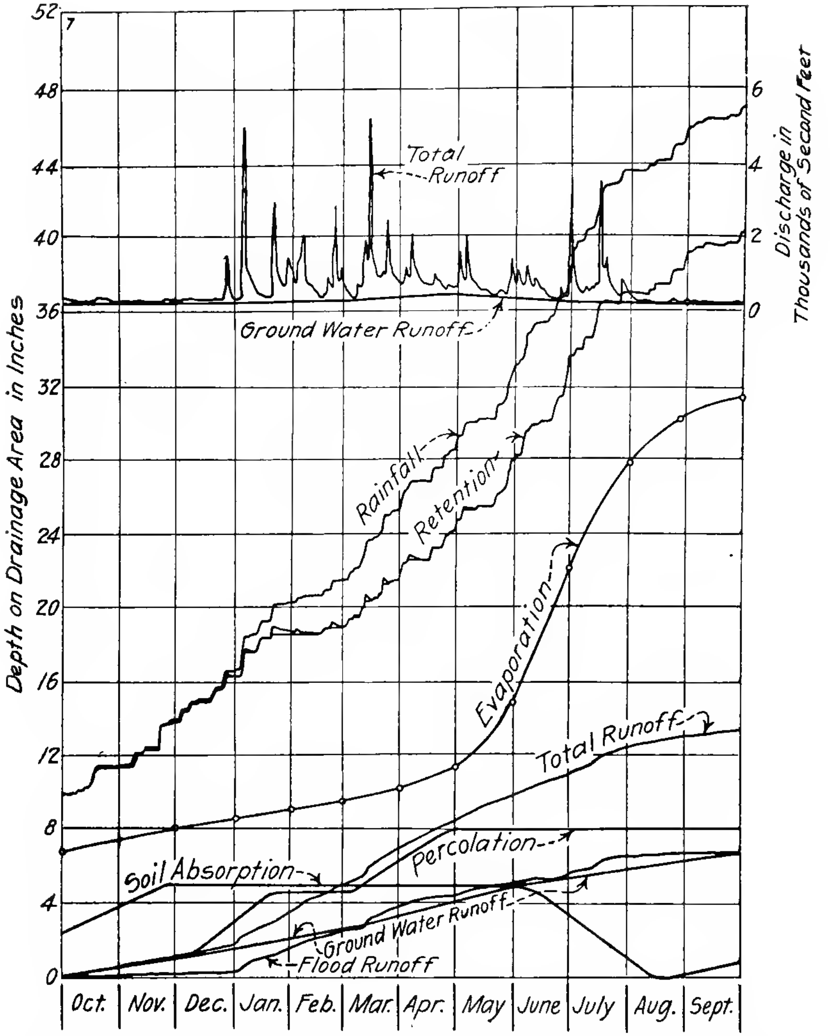

FIG. 37.—HYDROLOGY OF THE MAD RIVER VALLEY ABOVE WRIGHT DURING 1917.

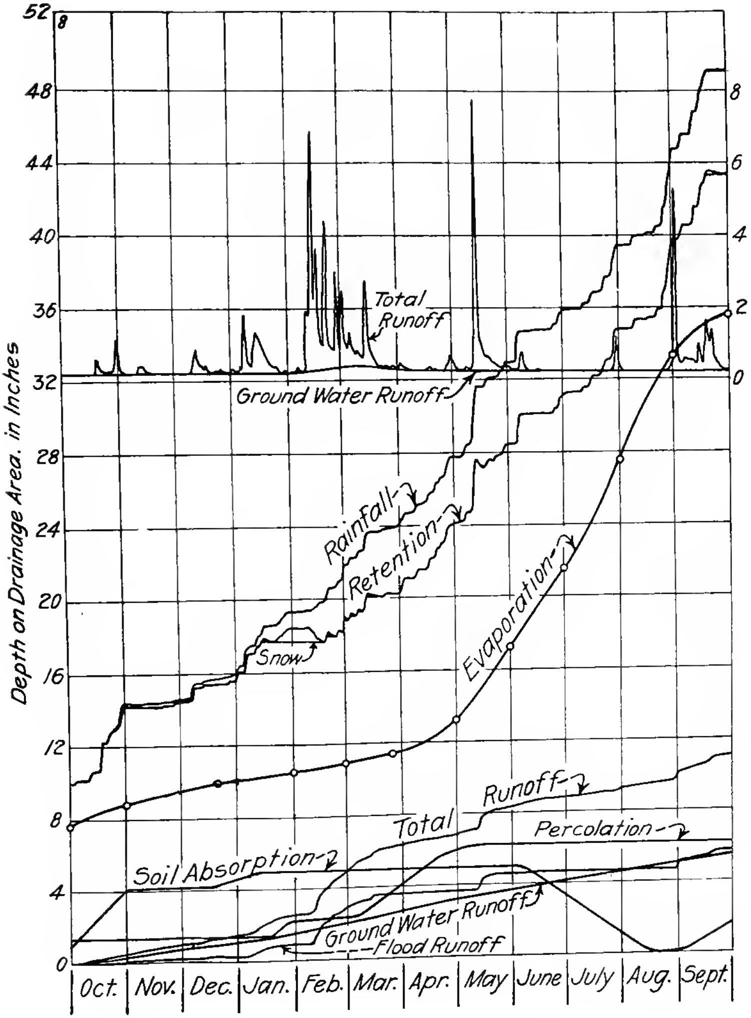

FIG. 38.—HYDROLOGY OF THE MAD RIVER VALLEY ABOVE WRIGHT DURING 1918.

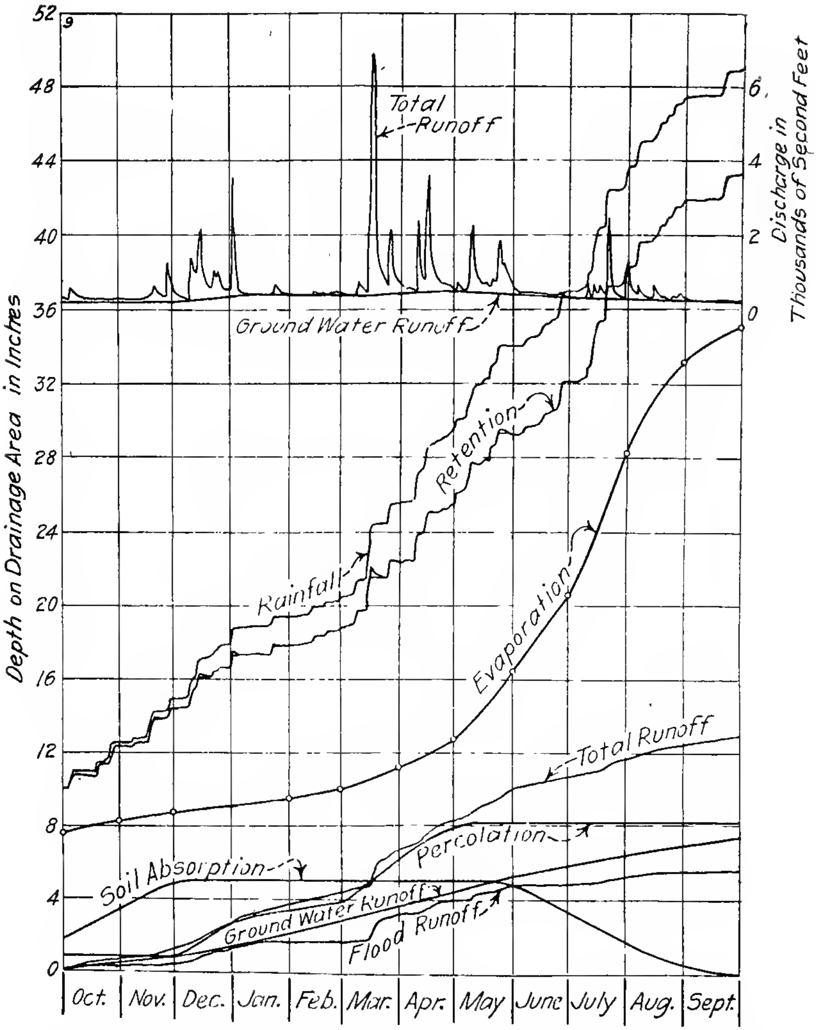

FIG. 39.—HYDROLOGY OF THE MAD RIVER VALLEY ABOVE WRIGHT DURING 1919.

flood runoff from ground water runoff are platted in the upper parts of the figures.

No explanation of the four curves mentioned first is needed. They were simply drawn from the rainfall and runoff data determined as previously described. The retention curve was obtained by subtracting the flood runoff from the rainfall. Horizontal lines have been drawn under the peaks, or humps, on the retention curves, thus indicating the surface storage. The larger humps, having a comparatively long duration and occurring during the winter months, are due to precipitation in the form of snow. The two larger humps due to this cause have been marked "snow", but the others have not been designated. The sharp peaks of comparatively short duration represent storage on the ground or in the stream channels during flood periods. The retention curve, as modified by the horizontal lines, represents the total of the soil absorption, percolation, and evaporation curves, the ground water runoff being maintained by the ground water storage or percolation water. The lines under the humps should really have been drawn so as to slope upward toward the right instead of horizontal, since soil absorption and evaporation are continuous, to some extent at least, throughout the storm period.

The soil absorption curves, or soil storage curves as they might be termed, were drawn after a careful study of the Moraine Park soil moisture records given in chapter III. It was assumed that there is a variation of five inches in the amount of moisture in the soil during the year; that the soil reaches its dryest condition sometime late in the summer, during August or September; that it gradually fills with moisture in the fall, during the months of September, October, November, and December; and that it then remains saturated until late in the spring, when it begins to dry out due to transpiration and increased soil evaporation.

In drawing the percolation curves it was assumed that no percolation occurs during the summer or early fall months; that is, that percolation ceases about the time the soil begins to dry out in the spring and does not begin until late in the fall, about the time the surface soil becomes saturated. It was also assumed that the percolation curve joins the ground water runoff curve at the time percolation begins. The former assumption is believed to be essentially correct for the Miami Valley except in very unusual instances. The latter assumption, while more

or less arbitrary, does not lead to appreciable error. Of course the percolation curves do not need to touch the ground water runoff curves at the time percolation begins. They could have been drawn a fixed distance above, at this time; that is, the curves shown in the figures could have been arbitrarily raised a certain amount.

By drawing the percolation curves in this way the total percolation during a given winter and spring was made just great enough to maintain the ground water flow until percolation began in the following fall or winter. It is not believed that in the Miami Valley percolation during a given storage period ever affects greatly the ground water flow after percolation begins in the succeeding fall; or, in other words, that the ground water level at the time percolation begins ever varies greatly from year to year. The minimum amount of annual ground water runoff in the Miami Valley above Dayton occurred in 1902, following a year in which the rainfall was only 30.1 inches, or about 7 inches less than normal. In 1914, when the rainfall was 32.3 inches, or about 5 inches less than normal, following a year in which the rainfall was 42.9 inches, or about 6 inches more than normal, the ground water runoff amounted to 3.38 inches, or about 1.18 inches more than in 1902. A part of this 1.18 inches was probably due to the 2 inches greater rainfall in 1914. It does not seem probable that percolation during a particularly wet season ever increases the ground water runoff during the following year by as much as an inch.

In drawing the percolation curves during the winter and spring when percolation was taking place, consideration was given to the rainfall distribution and form of occurrence as well as to the temperature and other meteorological conditions.

The evaporation curves were determined by subtracting from the retention curves, or from the horizontal lines under the retention curves, the sum of the soil absorption and percolation curves. In doing this points were taken about a month apart as shown on the diagrams. The attempt was to show the general shape of the evaporation curve throughout the year rather than the daily variations. It is only at the points indicated that the evaporation is equal to the retention less the sum of the soil absorption and percolation. In order for this relation to hold throughout it would be necessary to throw the small irregularities of the retention curves into the evaporation, absorption, or percolation curves. It is probable that during the summer and fall the ir-

regularities should be thrown into the evaporation and absorption curves; and that during the winter and spring they should be thrown into the evaporation and percolation curves. More irregularities would be expected in the evaporation curve during the summer than during the winter. Data on transpiration and soil evaporation seems to indicate that during the summer months rates of evaporation as great as a half an inch a day, or even greater, may occur immediately after a heavy rain. Such conditions would cause jumps in the evaporation curve somewhat similar to those in the retention curve.

Table 31 gives the monthly evaporation, taken from the curves, for the Mad River Valley above Wright for each year; and also the average amount for each month, based on the five years' records. The average monthly evaporation from a water

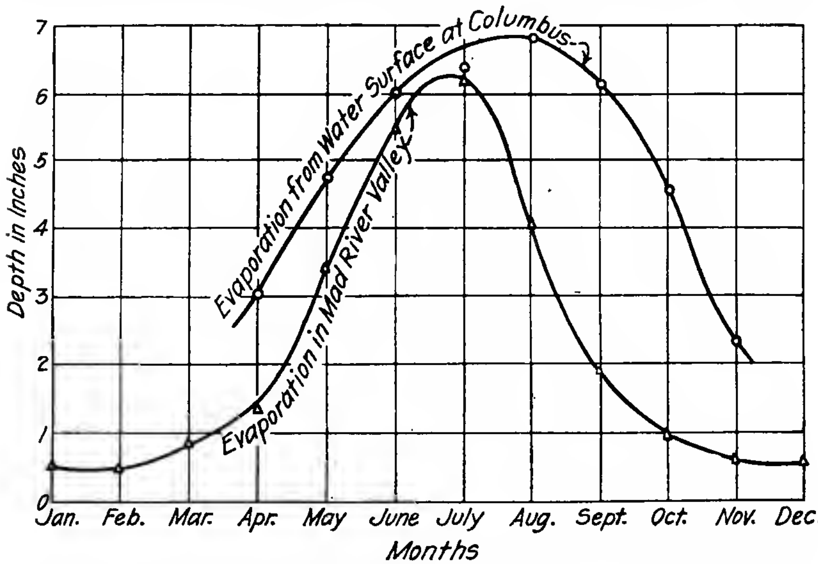

FIG. 40.—MONTHLY EVAPORATION IN THE MAD RIVER VALLEY ABOVE WRIGHT

For comparative purposes a curve has been added showing the monthly evaporation from water surface at Columbus.

surface at Columbus, for the years 1907 and 1908, for the months of April to November is also included.* Figure 40 shows graphically the data on average monthly evaporation given in table 31. It will be noticed that the evaporation from a water surface is

*Water Resources of Illinois by A. H. Horton, Report of Rivers and Lakes Commission, State of Illinois, Springfield, Illinois, 1914, page 310.

somewhat higher than the evaporation from the land, especially during the fall months. The evaporation from the land is comparatively low during the fall because the available supply of moisture has been depleted by the high rates of transpiration and soil evaporation during the growing season.

Table 31.—Monthly Evaporation on Drainage Area Above Wright Station, in inches, 1915 to 1919, inclusive

Month	Years					Average	Average Evaporation* from Water Surface
	1915	1916	1917	1918	1919		
October....	1.04	1.18	.63	1.20	.65	.94	4.58
November..	.67	.57	.57	.70	.48	.60	2.35
December.	.67	.60	.55	.53	.42	.55	....
January....	.55	.55	.55	.52	.40	.51	....
February...	.47	.48	.45	.40	.55	.47	....
March.....	.80	.85	.75	.60	1.20	.84	....
April.......	1.20	1.17	1.15	1.60	1.50	1.32	3.05
May.......	1.70	3.90	3.60	4.15	3.70	3.41	4.73
June.......	5.15	6.30	7.20	4.30	4.25	5.44	5.99
July.......	7.60	4.05	5.65	5.90	7.70	6.18	6.37
August.....	4.15	2.60	2.65	5.95	4.95	4.06	6.81
September..	2.60	1.90	.95	2.15	1.80	1.88	6.11
Total	26 60	24.15	24.70	28.00	27.60	26.21	....

*Based on records taken at Columbus, 1907–1908.

Table 32.—Seasonal Evaporation in Mad River Valley Above Wright, in Inches

Season	Years					Average
	1915	1916	1917	1918	1919	
Replenishing Period.....	2.38	2.35	1.75	2.43	1.55	2.09
Storage Period..........	3.02	3.05	2.90	3.12	3.65	3.15
Growing Period.........	21.20	18.75	20.05	22.45	22.40	20 97
Total	26 60	24.15	24.70	28.00	27.60	26.21

Table 32 gives the seasonal evaporation for the Mad River Valley calculated from the data in table 31. The data indicates that, on the average, about 80 per cent of the annual evaporation occurs in the growing period, during the months of May to September, inclusive. This leaves only 20 per cent for the replenishing and storage periods, or the seven months from October to April, inclusive.

CHAPTER VI.—RAINFALL AND RUNOFF DURING 1913 FLOOD

The flood of March, 1913, was not only the most severe of which there is record in this valley, but as regards damage was also the greatest that has occurred in the eastern half of the United States since the days of first settlement, or since floods first began to attract attention. A description of this flood and of the damage it wrought has been published in an earlier report.*

It was caused primarily by hard rains which commenced on March 23, and continued with but little interruption until the 27th. Contributing factors were a saturated soil when the rain began, as a result of previous rains, and low temperatures which reduced evaporation to insignificant rates and affected the percolation of water through the soil.

Being the maximum flood on record it was necessary, of course, to make detailed investigations of the rainfall and runoff for use in the design of the flood prevention works. The hydraulic design of the works has been described in volume VII of the technical reports.† The results of such studies were also needed in determining the benefits and damages resulting from the construction of the retarding basins.

This chapter will give the rainfall and runoff date secured, and will discuss the various studies which were made immediately following the flood.

RAINFALL

The daily rainfall over the Miami River drainage area during the storm of March, 1913, is shown in figure 41. Maps are included showing one-inch isohyetals for the 24-hour periods ending at 7 p. m. of March 23, 24, 25, and 26. A map for March 27 has not been reproduced because the precipitation on that day amounted to only about half an inch. Figure 42 shows the total

*The Miami Valley and the 1913 Flood, by Arthur E. Morgan, Chief Engineer, Technical Reports, Part I, The Miami Conservancy District, Dayton, Ohio, 1917.

†Hydraulics of the Miami Flood Control Project, by S. M. Woodward, Technical Reports, Part VII, The Miami Conservancy District, Dayton, Ohio, 1920.

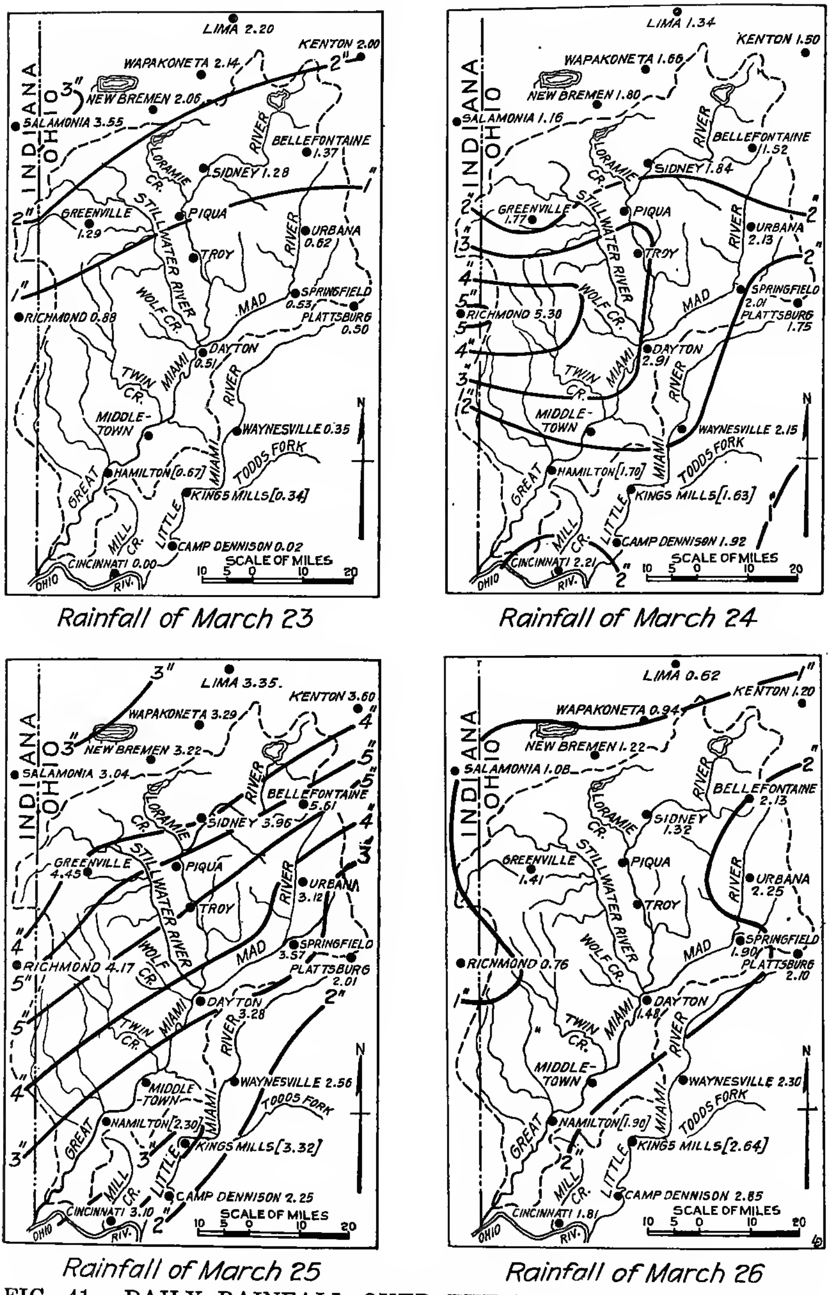

FIG. 41.—DAILY RAINFALL OVER THE MIAMI VALLEY DURING THE STORM OF MARCH, 1913.

The amounts recorded at the various stations are indicated by the figures written after the names of the stations.

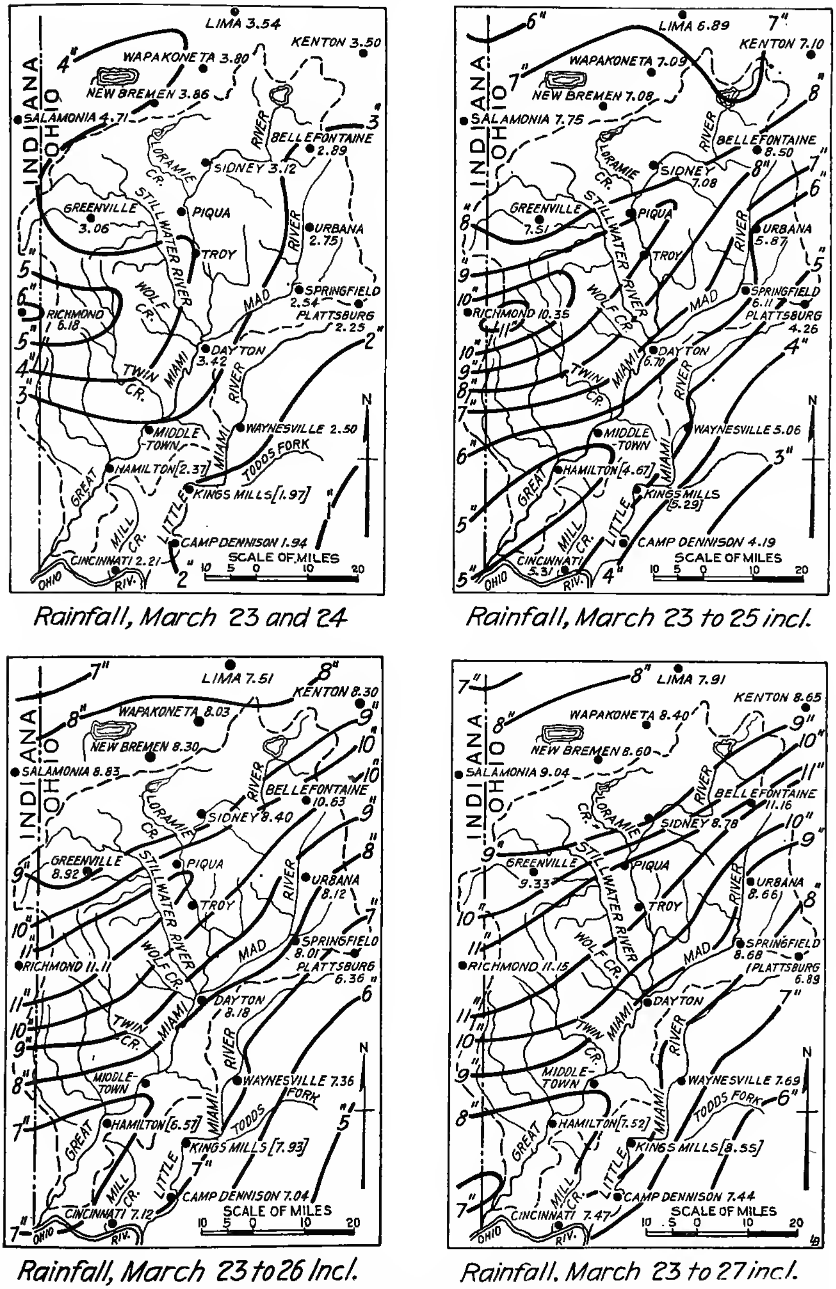

FIG. 42.—CUMULATED RAINFALL OVER THE MIAMI VALLEY DURING THE STORM OF MARCH, 1913.

Rainfall shown on each map is the total from the beginning of the storm up to 7 p. m. of the second date noted under the map.

accumulated precipitation for the periods ending at 7 p. m. of March 24, 25, 26, and 27.

The amounts of rainfall recorded at the various places where gages are maintained are shown by the figures placed after the names of the stations. At the river stations, where the rainfall is measured in the morning, the amounts estimated for the 24-hour periods ending at 7 p. m. are enclosed in brackets.

Fortunately there were a number of well distributed rain gages in this part of the Ohio Valley in 1913. Reports from about 50 stations were utilized in the preparation of figures 41 and 42, many of which were outside the area shown on the maps, some being in Indiana and Kentucky. Although Dayton was the only regular Weather Bureau station located within the Miami Valley at that time, there were several in nearby cities, as at Cincinnati, Indianapolis, Fort Wayne, Toledo, Sandusky, and Columbus. Only a partial graphical record of rainfall was secured at Dayton. Owing to the flooding of the business section of the city, in which the office is located, the triple register could not be kept in operation, the clock stopping at 4:30 p. m. on March 25.

Figure 43 shows the distribution of the precipitation, as regards time, at the above mentioned regular stations, platted from data published by the U. S. Weather Bureau in Bulletin Z.* The abscissas represent time, and the ordinates, the amount of rainfall in inches per hour, the amounts being shown by horizontal lines extending through the hours in which they occurred. Since the actual amounts used in platting the horizontal lines were usually for one-hour periods, the ordinates, in such cases, indicate the total precipitation for each hour as well as the rate. The total rainfall for any length of time at a given station is represented by the area under the portion of the curve corresponding to that time; that is, by the product of the rate and its duration.

Hourly readings were not available for March 27, or for March 26 at Fort Wayne. The precipitation in the latter instance, and probably in the former at some stations, was in the form of snow. Since the precipitation was small in both cases the rates have been computed and platted as having continued

*The Floods of 1913 in the Rivers of the Ohio and Lower Mississippi Valleys, by Alfred J. Henry, Meteorologist, Bulletin Z, U. S. Weather Bureau, Washington, D. C., 1913.

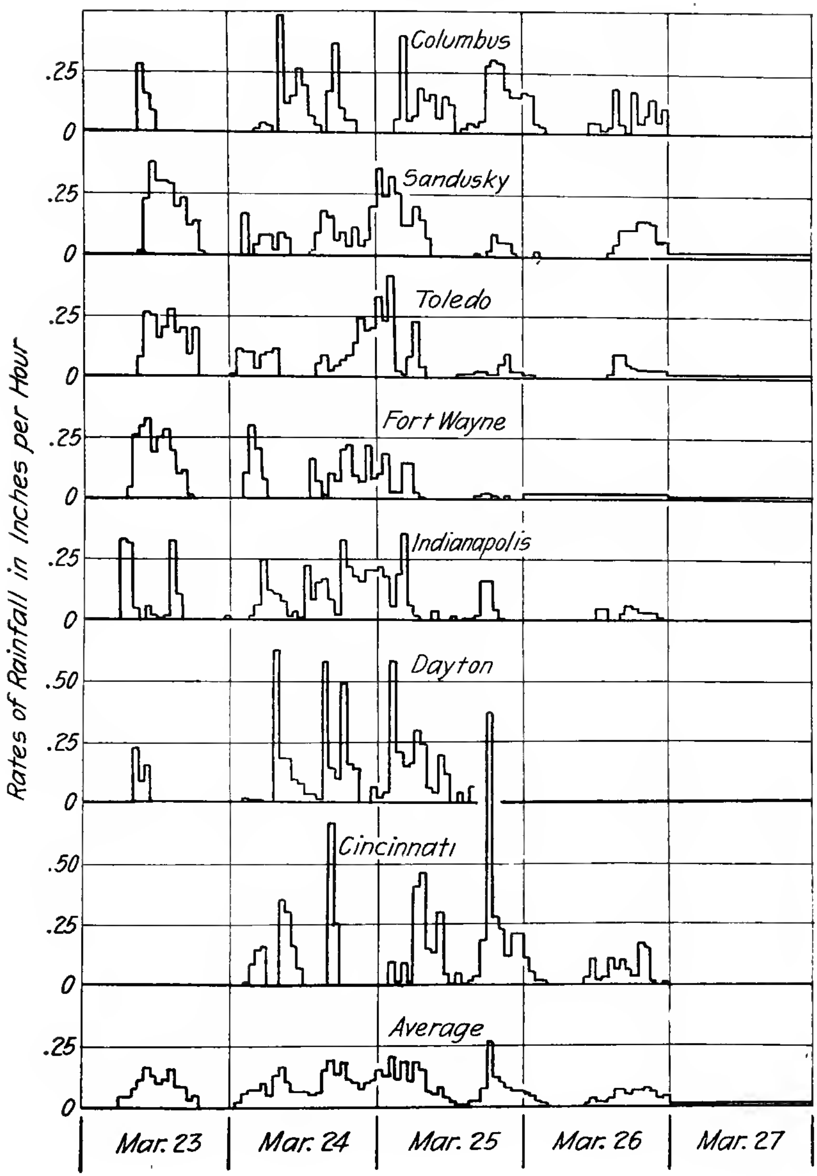

FIG. 43.—HOURLY RAINFALL AT STATIONS NEAR THE MIAMI VALLEY DURING THE STORM OF MARCH, 1913.

Based on graphical records at the U. S. Weather Bureau stations.

uniformly throughout the 24 hours. The actual rainfall on the 27th probably ended by evening or sooner.

It will be noticed that the rain seemed to occur in showers at the various stations, the showers being a little more intense at Cincinnati and Dayton than at the other cities. The times of occurrence of the principal showers at the different places seem to agree fairly well. Consequently, a curve has been added showing the average hourly amount based on the seven actual records. Although the total precipitation over the Miami Valley above Dayton determined from the isohyetal map in figure 42 amounted to 9.60 inches while the total determined from the curve in figure 43 amounted to only 6.40 inches, this curve is the only available indication of the rainfall distribution above Dayton.

It appears that the rainfall began during the morning of the 23rd and continued during the greater part of the day, ending at about the time the daily readings were being taken by the co-operative observers. The average over the Miami Valley above Dayton amounted to 1.20 inches. The precipitation was heaviest in the northern part of the drainage area. The rain began again about midnight and fell almost continuously throughout the 24th, 25th, and 26th. On the 24th the total up to 7 p. m. averaged 2.20 inches above Dayton, the greatest precipitation occurring over the headwaters of Twin Creek, further south than on the preceding day. The greatest rainfall occurred on the 25th, averaging 4.11 inches, and registering a maximum of 5.61 inches at Bellefontaine, about 55 miles northeast of Dayton. It was on the morning of this date that the rivers, which had been steadily rising, overtopped the levees in the principal cities. Near the following midnight the highest stages were attained at places between Dayton and Hamilton. On the 26th the average rainfall amounted to 1.62 inches; on the 27th it amounted to 0.47 inches. The latter was of little consequence, however, as the waters were then everywhere receding rapidly.

RUNOFF

Unfortunately there were only three river gages in the Miami Valley at the time of the flood. These were the gages maintained by the U. S. Weather Bureau at Piqua and Dayton and by the U. S. Geological Survey at Hamilton. Discharge measurements during flood stages had been secured only at Hamilton.

During the summer and fall following the flood, extensive hydrographic surveys were made for the purpose of determining

the maximum rates of discharge at various places along the streams. These surveys and the methods used in calculating the maximum rates of runoff have been described in an earlier report.* The results obtained are shown on the map in figure 44. At each location where measurements were made the quantities are indicated by means of a fraction and a quotient. The numerator represents the maximum total rate of discharge in second feet at the given place; the denominator, the drainage area in square miles above that place; and the quotient, the maximum rate of runoff in second feet per square mile over the given drainage area. It will be noticed that the rates of runoff are unusually high at all places. However, in the case of the smaller drainage areas, these rates continued for but small fractions of a day.

Figure 45 shows the hydrographs of the 1913 flood at Piqua, Dayton, and Hamilton. These were determined as accurately as possible from the gage readings taken during the flood, from the maximum rates of discharge based on the surveys, and from current meter gagings made during subsequent smaller floods. The rates of runoff in inches per day over the drainage areas are platted as ordinates, and the times, as abscissas. For comparative purposes the average curve of hourly rainfall obtained in figure 43 has also been included.

It will be noticed that the rates of runoff above Piqua were lower than those above Dayton and Hamilton, throughout the entire flood period. The rates above Dayton and Hamilton agree very well. It is believed that the reasons for the lower rates of runoff above Piqua are the less intense precipitation above that station, the storage in the Loramie and Lewistown reservoirs, which has been estimated to be equivalent to a depth of about a quarter of an inch over the total drainage area above Piqua, and the somewhat less rolling topography in the upper parts of the valley.

Considering the steeply rising portions of the hydrographs there seems to have been a difference in time of about 6 hours between the Piqua and Dayton curves, and of about 8 hours between the Dayton and Hamilton curves. It will be noticed that at Piqua the river reached its crest at about 10 o'clock Tuesday morning, March 25, and then remained stationary about four hours. At Dayton, however, the maximum stage was not reached until about midnight Tuesday, although the river was within a

*Calculation of Flow in Open Channels, by Ivan E. Houk, Technical Reports, Part IV, The Miami Conservancy District, Dayton, Ohio, 1918.

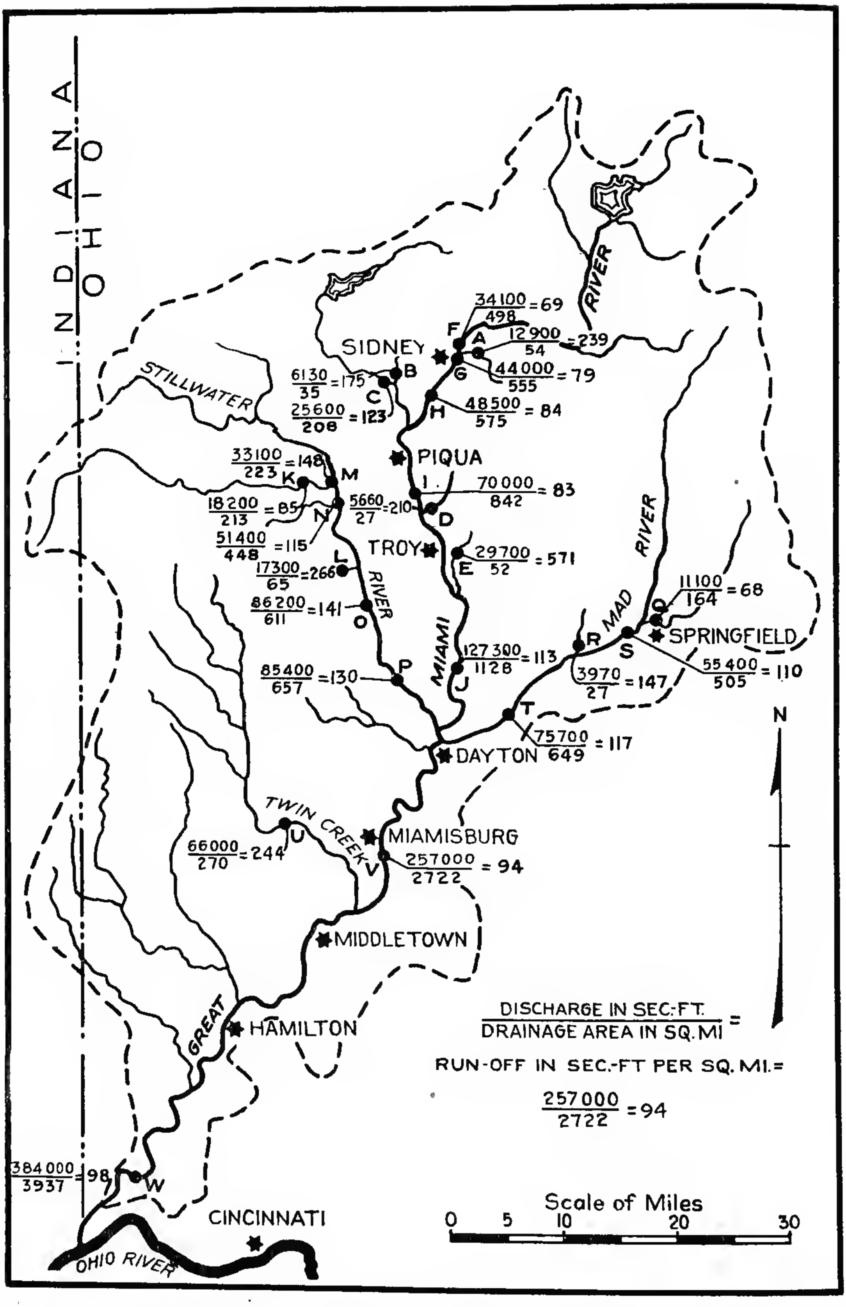

FIG. 44.—MAXIMUM RATES OF RUNOFF IN THE MIAMI VALLEY DURING THE FLOOD OF MARCH, 1913.

The figures are written opposite the places at which measurements were made subsequent to the flood, and give the runoff in second feet per square mile as indicated in the lower right hand corner.

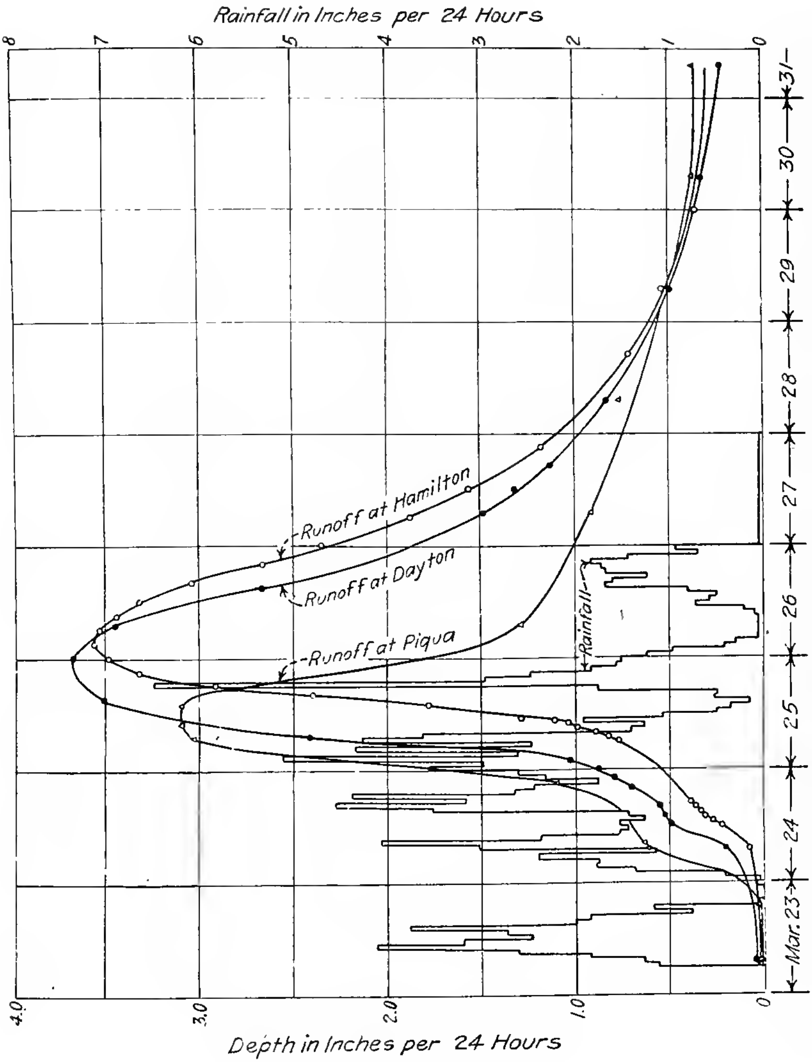

FIG. 45.—HYDROGRAPHS OF 1913 FLOOD AT PIQUA, DAYTON, AND HAMILTON.
For comparison the average rainfall curve determined in figure 44 has been added.

foot of its highest stage at noon. At Hamilton the crest was reached at about 3 a. m. Wednesday, March 26. Investigations made within a few weeks after the flood showed that the Stillwater River just above Dayton reached its crest at about noon Tuesday; that the Miami River above its junction with the Stillwater reached its crest at about 7 p. m. Tuesday evening; and that the Mad River above the Miami reached its crest at about midnight Tuesday. In each case the river remained practically stationary for a few hours before it began to fall. Consequently the highest stage at Dayton was due to the coordination of the highest stages in the Upper Miami and Mad Rivers. If the crest in the Stillwater had been delayed a few hours the stage at Dayton would have been higher than it actually was.

Owing to the distribution of the most intense rainfall as regards drainage areas as well as regards time, the highest stages in the various streams were caused by the local runoff rather than by the runoff from the upper drainage areas. No indications of the occurrence of a definite flood wave were found, except, possibly, in the case of Mad River. In this instance the investigations seemed to indicate a difference in the time of crest of about 12 hours between Springfield and Dayton, a distance of about 25 miles. The comparatively slow movement of the crest was due to the great amount of storage in the valley. The Stillwater River was at its crest at practically the same time from Covington to Dayton, a distance of about 30 miles; as was also the Miami from DeGraff to Tippecanoe City a distance of about 45 miles.

RELATION OF RUNOFF TO RAINFALL

Reference to figure 45 shows that while the rainfall curve is comparatively irregular the runoff curves are comparatively smooth. This is because the runoff curves are for large drainage areas, 842 to 3672 square miles. In such cases the irregularities of the rainfall tend to be eliminated by the effects of storage on the ground and in the numerous small tributary drains, as well as by the time required for the runoff to reach the main streams. The conditions may be said to be analagous to the operation of a retarding basin, the rainfall curve corresponding to the inflow to the basin, and the runoff curves, to the outflow. The runoff curve for a drainage area of a few square miles would un-

doubtedly have shown irregularities corresponding to those in the rainfall curve.

It will be noticed that considerable rainfall occurred during the first two days, while in the same period there was comparatively little runoff. It also appears that when the rainfall ceased rather abruptly, the runoff continued for several days afterwards. This condition was due to the surface storage mentioned above, the water held by the small depressions and irregularities in the surface of the ground, as well as in the stream channels, draining out gradually after the rainfall ceased.

In order to consider properly the total surface runoff resulting from the rainfall of March 23 to 27, it is necessary to keep in mind the weather and ground conditions preceding the storm. January was an unusually wet month, the total precipitation, which was well distributed through the month, amounting to over seven inches. February was drier than usual, the rainfall totaling an inch less than the normal of three inches for that month, and occurring mostly in the last three days. March was wet throughout. From the first to the 21st moderate rains were recorded at all of the gaging stations on about ten days. On the 21st the precipitation throughout the valley averaged nearly a half an inch.

It is evident from these conditions that at the beginning of the rain on March 23 the ground was fully saturated, that the ground water flow was greater than usual, and that there was some surface runoff in the streams as a result of the precipitation of March 21. The latter factor can be eliminated in the determination of the flood runoff, caused by the storm of March 23 to 27, by totaling the runoff only to the time when the amount of water in the stream channel was the same as when the flood began. This time was estimated to be in the evening of March 31.

However, the effect of the ground water flow must be allowed for in a different manner, since some runoff was being maintained by underground storage during the entire flood period. From a study of the daily discharges before and after the flood it is estimated that 0.05 of an inch per day should be deducted from the total runoff, in order to obtain the true surface, or flood, runoff. As nearly as can be determined this amount would be the same for Piqua, Dayton, and Hamilton.

Figure 46 shows mass curves of rainfall, flood runoff, and retention for the flood of March, 1913. Rainfall and retention curves are shown only for the total drainage area above Dayton;

flood runoff curves are shown for Piqua, Dayton, and Hamilton. The rainfall curve was calculated from the average curve shown in figure 45, arbitrarily raising the latter so that the total precipitation for each day agreed with the value determined from the isohyetal map in figure 41. The flood runoff curves were likewise calculated from the rate curves of figure 45, deducting the ground water flow from the total, as mentioned above. The retention curve is simply the difference between the rainfall curve and the Dayton flood runoff curve.

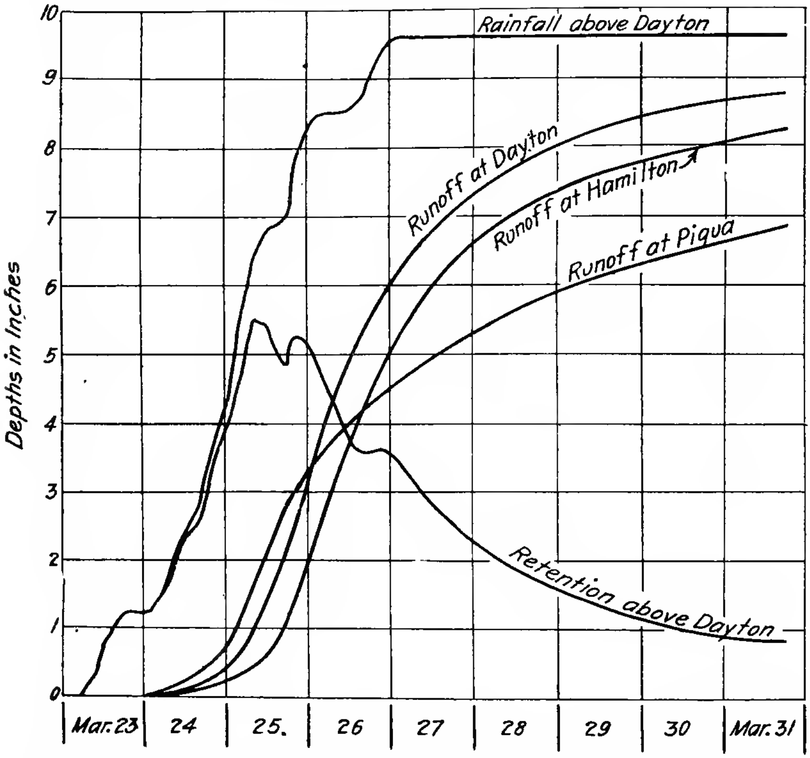

FIG. 46.—RAINFALL, RUNOFF, AND RETENTION DURING THE FLOOD OF MARCH, 1913.

Curves show total values of the various quantities up to any instant.

The retention represents soil absorption, evaporation, and storage on the ground and in the streams. That soil absorption and evaporation were comparatively unimportant during this flood is indicated by the fact that the curve falls rapidly after the most intense precipitation ceased, reaching a value of about 0.84 inches by the evening of March 31. That this would be true

was indicated, of course, by the previous rainfall and weather conditions described above.

The maximum retention occurred at about 8 a. m., March 25, amounting to 5.50 inches. If it is estimated that the total soil absorption and evaporation up to this time had amounted to a half an inch, the storage on the ground and in the streams would be about 5 inches. Of this amount it is probable that the proportion held in the main channels and in the adjacent overflow sections was about 2 inches, and the portion held in the small streams and ponds and on the ground surface, about 3 inches.

Table 33 gives the daily rainfall and flood runoff for each day of the flood, for Piqua, Dayton, and Hamilton. The values

Table 33.—Daily Rainfall and Runoff Above Piqua, Dayton, and Hamilton During the 1913 Flood, in Inches

Date	Piqua		Dayton		Hamilton	
	Rainfall	Runoff	Rainfall	Runoff	Rainfall	Runoff
March 23	1.57	......	1.20	......	1.00	......
24	1.77	0.43	2.20	0.25	2.40	0.10
25	4.14	2.43	4.11	2.12	4.04	1.11
26	1.50	1.41	1.62	3.20	1.62	3.30
27	0.40	0.87	0.47	1.52	0.51	1.85
28	......	0.64	......	0.79	......	0.87
29	......	0.46	......	0.46	......	0.47
30	......	0.32	......	0.26	......	0.29
31	......	0.29	......	0.16	......	0.22
Totals for flood	9.38	6.85	9.60	8.76	9.57	8.21
Ratio of runoff to rainfall	......	73.0	......	91.2	......	85.8
Total retention, in inches	......	2.53	......	0.84	......	1.36

of daily rainfall were obtained from the isohyetal maps in figure 41, and the values of daily runoff, from the mass curves of figure 46. The amounts are for the 24 hours ending at 7 p. m. in all cases. Total quantities for the flood period and ratios of total runoff to total rainfall are given at the bottom of the table.

It will be noticed that the total runoff at Piqua was somewhat smaller than at Dayton and Hamilton. The total at Piqua amounted to 6.85 inches, or to only about 73 per cent of the rainfall, while the total at Dayton was 8.76 inches, or about 91 per cent of the rainfall, and at Hamilton, 8.21 inches, or about 86 per cent of the rainfall. The total amounts at Dayton and Hamilton agree very well. The conditions believed to be responsible for the smaller runoff above Piqua have already been mentioned.

CHAPTER VII.—RAINFALL AND RUNOFF DURING FLOODS SINCE MARCH, 1913

Since March, 1913, only floods of nominal size have occurred in the Miami Valley. During the 1913 flood, the maximum stage at Dayton was 29 feet, or 6 feet above the levees. The highest water since that time was during the flood of April, 1920, when the maximum stage was 16.2 feet, or about 7 feet below the tops of the levees. Practically no flooding has occurred within the cities during this period although farm lands near the various streams have been flooded several times. However, this flooding generally occurred during the winter and early spring months, when but little if any damage was sustained.

RAINFALL, RUNOFF, AND RETENTION DURING FLOODS

Table 34 gives the total rainfall, runoff, and retention in inches, and the ratio of the total runoff to the total rainfall, in per cent, for the larger floods. The dates of the storm periods are given in the table headings. The dates of the flood periods have not been indicated. In general, however, they began shortly after the storm rainfall began and continued from two to five days after the rainfall ceased, the exact time, of course, varying with the nature of the storm and with the topography and extent of the drainage area. For comparative purposes the sizes of the drainage areas above the various stations, have been included. The topography and geology of the Miami Valley have been discussed briefly in chapter I. A map of the valley showing the gaging stations is given in figure 1, page 17.

The values of rainfall included in the table are averages for the drainage areas, for the entire storm periods. They were determined by planimeter measurements on isohyetal maps, similar to those in figures 41 and 42, pages 178 and 179. The values of runoff represent the total flood or surface runoff caused by the indicated rainfall. The runoff maintained by the ground water storage has been deducted in each case, as in the determination of the 1913 flood runoff. The values of retention are simply the

differences between the storm rainfall and the flood runoff. The value for a given storm includes the total amount of moisture taken up by the soil and the total evaporation during the storm period. Storms are arranged chronologically.

The data for the larger drainage areas is believed to be more accurate than most similar data which has been published. The valley is well supplied with rainfall stations, as shown in figure 1; the rating curves on the principal streams have been well developed; and the main portions of the flood hydrographs were determined by special readings taken every hour or every two hours. While the data for the smaller areas is not so accurate, it is believed that with one or two exceptions the errors are not excessive.

DESCRIPTIVE NOTES

On account of the condensed form in which the data in table 34 is presented it has not been feasible to include descriptive notes. Since such notes are desirable in any study of the subject, they are given in the following paragraphs.

July 7-8, 1915

The rainfall in the Miami Valley during the storm of July 7 to 8, 1915, was most intense in the evening of the 7th, from about nine to about ten o'clock. Practically the entire precipitation fell sometime during that evening, only a few hundredths of an inch falling after midnight. Although a half an inch fell on the 11th and 12th, it has not been included in the storm as it caused no surface runoff. The most intense precipitation at Moraine Park has been shown graphically in figure 9, page 80.

The soil moisture experiments carried on at Moraine Park, described in chapter III, show that the soil was not saturated when the rain began, although some rain had fallen each day during the period from July 1 to 5, inclusive, and although the total precipitation during the month of June had been slightly greater than normal. In fact, observations made on the 8th, after the rain had ceased, showed that even then the soil was not saturated to a depth of 6 inches.

The streams began rising about 9 p. m. of the 7th. Highest stages were recorded sometime during the 8th in the upper portions of the valley; on the morning of the 9th at Dayton; and during the evening of the 8th at Hamilton; the crest at Hamilton

Table 34.—Total Rainfall, Runoff, Retention, and Ratio of Runoff to Rainfall during Various Floods since March, 1913

Gaging Station	Drainage Area Square Miles	Storm of July 7–8, 1915				Storm of December 24, 1915, —January 7, 1916				Storm of January 10-13, 1916				Storm of January 26-31, 1916			
		Rainfall in Inches	Runoff in Inches	Retention in Inches	Ratio of Runoff to Rainfall in per cent	Rainfall in Inches	Runoff in Inches	Retention in Inches	Ratio of Runoff to Rainfall in per cent	Rainfall in Inches	Runoff in Inches	Retention in Inches	Ratio of Runoff to Rainfall in per cent	Rainfall in Inches	Runoff in Inches	Retention in Inches	Ratio of Runoff to Rainfall in per cent
Sidney........	555	1.94	0.65	1.29	33.	3.90	2.68	1.22	69.	1.56	0.90	0.66	58.	2.56	2.19	0.37	85.
Lockington....	255	Gage	install	ed 9–1	3–1915	4.14	3.57	0.57	86.	1.45	1.32	0.13	91.	3.21	2.90	0.31	90
Piqua........	842	2.05	1.16	0.89	57.	3.97	3.13	0.84	79.	1.52	1.06	0.46	70.	2.90	2.38	0.52	82.
Tadmor.......	1128	2.10	0.85	1.25	40.	3.89	2.88	1.01	74.	1.61	0.94	0.67	58.	2.91	2.24	0.67	77.
West Milton...	600	2.89	1.40	1.49	48.	3.99	2.99	1.00	75.	1.74	0.81	0.93	47.	3.56	3.40	0.16	95.
Buck Creek....	163	1.95	0.21	1.74	11.	3.16	0.60	2.56	19.	1.69	0.59	1.10	35.	1.96	0.62	1.34	32.
Springfield.....	488	2.09	0.46	1.63	22.	3.65	0.95	2.70	26.	1.83	0.70	1.13	38.	2.07	0.88	1.19	42.
Wright.......	652	2.09	0.51	1.58	24.	3.41	1.26	2.15	37.	1.82	0.80	1.02	44.	2.33	0.99	1.34	42.
Dayton.......	2525	2.30	0.81	1.49	35.	3.73	2.47	1.26	66.	1.73	1.03	0.70	60.	2.89	2.13	0.76	74.
Germantown...	272	2.99	1.41	1.58	47.	3.30	2.42	0.88	73.	2.09	1.45	0.64	69.	3.47	2.68	0.79	77.
Seven Mile....	128	2.53	1.10	1.43	43.	2.68	2.18	0.50	81.	1.85	1.79	0.06	97.	3.27	3.81	—0.54	116.
Four Mile.....	178	2.16	1.46	0.70	68.	2.82	2.26	0.56	80.	1.93	2.41	—0.48	125.	2.99	4.07	—1.08	136.
Hamilton......	3672	2.32	0.75	1.57	32.	3.42	1.55	1.87	45.	1.86	1.14	0.72	61.	2.88	2.09	0.79	73.

Table 34.—*Continued*

Gaging Station	Drainage Area Square Miles	Storm of March 21-22, 1916				Storm of March 25-28, 1916				Storm of May 6-7, 1916				Storm of January 3-6, 1917			
		Rainfall in Inches	Runoff in Inches	Retention in Inches	Ratio of Runoff to Rainfall in per cent	Rainfall in Inches	Runoff in Inches	Retention in Inches	Ratio of Runoff to Rainfall in per cent	Rainfall in Inches	Runoff in Inches	Retention in Inches	Ratio of Runoff to Rainfall in per cent	Rainfall in Inches	Runoff in Inches	Retention in Inches	Ratio of Runoff to Rainfall in per cent
Sidney........	555	1.48	0.96	0.52	65.	1.98	1.61	0.37	81.	1.85	1.04	0.81	56.	1.81	0.39	1.42	22.
Lockington....	255	1.13	0.99	0.14	88.	1.58	1.25	0.33	79.	2.22	2.00	0.22	90.	2.03	1.01	1.02	50.
Piqua.........	842	1.37	0.97	0.40	71.	1.84	1.54	0.30	84.	2.03	1.37	0.66	67.	1.88	0.71	1.17	38.
Tadmor.......	1128	1.25	0.81	0.44	65.	1.93	1.49	0.44	77.	2.00	1.09	0.91	55.	1.95	0.61	1.34	31.
Pleasant Hill...	453	Gage	install	ed 4-7	-1916	......	......	......	......	Data	not co	mpute	d	2.14	0.75	1.39	35.
West Milton...	600	0.84	0.49	0.35	58.	1.48	0.93	0.55	63.	1.58	0.75	0.83	47.	2.14	0.67	1.47	31.
Buck Creek....	163	1.04	0.33	0.71	32.	2.20	0.85	1.35	39.	2.58	0.19	2.39	7.	1.72	0.47	1.25	27.
Springfield.....	488	1.19	0.35	0.84	29.	2.34	0.90	1.44	38.	2.52	0.65	1.87	26.	1.90	0.50	1.40	26.
Wright.......	652	1.04	0.45	0.59	43.	2.33	1.03	1.30	44.	2.37	0.60	1.77	25.	1.90	0.44	1.46	23.
Dayton.......	2525	1.04	0.59	0.45	57.	1.89	1.32	0.57	70.	1.97	0.89	1.08	45.	1.99	0.67	1.32	34.
Franklin......	2785	0.99	0.54	0.45	55.	1.89	1.38	0.51	73.	1.90	0.89	1.01	47.	2.02	0.66	1.36	33.
Germantown...	272	0.43	0	0.43	......	1.79	0.72	1.07	40.	1.15	0.18	0.97	16.	2.28	1.08	1.20	47.
Seven Mile....	128	0.19	0	0.19	......	1.79	0.76	1.03	42.	0.70	0.18	0.52	26.	1.90	1.20	0.70	63.
Four Mile.....	178	0.18	0	0.18	......	1.65	0.55	1.10	33.	0.72	0.17	0.55	24.	2.11	0.82	1.29	39.
Hamilton......	3672	0.82	0.41	0.41	50.	1.81	1.11	0.70	61.	1.66	0.64	1.02	39.	2.07	0.70	1.37	34.

Table 34.—*Continued*

Gaging Station	Drainage Area Square Miles	Storm of March 11-14, 1917				Storm of June 26-29, 1917				Storm of July 12-17, 1917				Period of December 28, 1917 —February 15, 1918			
		Rainfall in Inches	Run-off in Inches	Retention in Inches	Ratio of Run-off to Rainfall in per cent	Rainfall in Inches	Run-off in Inches	Retention in Inches	Ratio of Run-off to Rainfall in per cent	Rainfall in Inches	Run-off in Inches	Retention in Inches	Ratio of Run-off to Rainfall in per cent	Rainfall in Inches	Run-off in Inches	Retention in Inches	Ratio of Run-off to Rainfall in per cent
Sidney	555	1.74	0.95	0.79	55.	2.27	0.29	1.98	13.	3.72	0.87	2.65	23.	4.02	2.05	1.97	51.
Lockington	255	2.07	1.70	0.37	82.	2.01	0.66	1.35	33.	2.96	1.37	1.59	46.	3.62	2.85	0.77	79.
Piqua	842	1.90	1.30	0.60	68.	2.20	0.47	1.73	21.	3.46	1.23	2.23	36.	3.89	Records missing		
Tadmor	1128	1.92	1.25	0.67	65.	2.38	0.45	1.93	19.	3.07	0.98	2.09	32.	3.95	2.02	1.93	51.
Pleasant Hill	453	2.07	1.67	0.40	81.	2.03	0.84	1.19	41.	2.49	0.92	1.57	37.	4.11	2.60	1.51	63.
West Milton	600	2.09	1.34	0.75	64.	1.86	0.46	1.40	25.	2.31	0.67	1.64	29.	4.04	2.99	1.05	74.
Buck Creek	163	1.73	0.31	1.42	18.	2.17	0.23	1.94	11.	2.37	0.31	2.06	13.	3.87	0.64	3.23	17.
Springfield	488	1.59	0.65	0.94	41.	2.56	0.37	2.19	14.	2.72	0.46	2.26	17.	4.24	0.98	3.26	23.
Wright	652	1.59	0.67	0.92	42.	2.47	0.33	2.14	13.	2.39	0.41	1.98	17.	4.29	1.20	3.09	28.
Dayton	2525	1.90	1.26	0.64	66.	2.25	0.40	1.85	18.	2.67	0.65	2.02	24.	4.07	1.92	2.15	47.
Franklin	2785	1.92	1.30	0.62	68.	2.19	0.45	1.74	21.	2.59	0.65	1.94	25.	4.10	1.57	2.53	38.
Germantown	272	2.63	1.47	1.16	56.	1.42	0	1.42	......	1.72	0.15	1.57	8.7	4.40	2.32	2.08	53.
Seven Mile	128	1.98	Records Missing			1.61	0	1.61	......	2.27	0.88	1.39	39.	4.69	3.35	1.34	71.
Four Mile	178	2.40	2.30	0.10	96.	1.56	0	1.56	......	2.55	0.17	2.38	6.7	4.80	1.63	3.17	34.
Hamilton	3672	1.97	1.24	0.73	63.	2.01	0.34	1.67	17.	2.47	0.58	1.89	23.	4.26	1.38	2.88	32.

Table 34.—*Continued*

Gaging Station	Drainage Area Square Miles	Storm of May 11-13, 1918				Storm of August 25-31, 1918				Storm of March 14-19, 1919				Storm of April 15-21, 1920			
		Rainfall in Inches	Run-off in Inches	Retention in Inches	Ratio of Run-off to Rainfall in per cent	Rainfall in Inches	Run-off in Inches	Retention in Inches	Ratio of Run-off to Rainfall in per cent	Rainfall in Inches	Run-off in Inches	Retention in Inches	Ratio of Run-off to Rainfall in per cent	Rainfall in Inches	Run-off in Inches	Retention in Inches	Ratio of Run-off to Rainfall in per cent
Sidney........	555	1.97	0.41	1.56	21.	2.51	0	2.51	......	3.07	1.72	1.35	56.	5.11	3.88	1.23	76.
Lockington....	255	1.64	0.29	1.35	18.	1.87	0	1.87	......	3.26	2.33	0.93	71.	4.79	4.13	0.66	86.
Piqua..........	842	1.87	0.38	1.49	20.	2.31	0	2.31	......	3.14	2.16	0.98	69.	5.00	3.93	1.07	79.
Tadmor.......	1128	2.03	0.57	1.46	28.	2.69	0.06	2.63	2.2	3.24	1.91	1.33	59.	4.75	3.38	1.37	71.
Pleasant Hill...	453	2.06	0.73	1.33	35.	2.25	0	2.25	......	3.48	2.78	0.70	80.	4.50	2.89	1.61	64.
West Milton...	600	2.17	0.54	1.63	25.	2.67	0	2.67	......	3.53	3.04	0.49	86.	4.46	3.08	1.38	69.
Buck Creek....	163	3.50	0.48	3.02	14.	4.51	0.54	3.97	12.	2.78	0.75	2.03	27.	5.05	1.13	3.92	22.
Springfield.....	488	3.27	0.53	2.74	16.	4.17	0.42	3.75	10.	3.10	1.16	1.94	37.	5.12	2.00	3.12	39.
Wright........	652	3.29	0 70	2.59	21.	4.30	0.41	3.89	9.5	3.04	1.16	1.88	38.	5.06	1.77	3.29	35.
Dayton.......	2525	2.45	0.63	1.82	26.	3.18	0.13	3.05	4.1	3.28	2.33	0.95	71.	4.75	2.91	1.84	61.
Franklin.	2785	2.53	0.67	1.86	26.	3.19	0.19	3.00	6.0	3.29	2.09	1.20	64.	4.72	2.82	1.90	60.
Germantown...	272	2.87	1.23	1.64	43.	3.27	0.42	2.85	13.	4.21	2.50	1.71	59.	4.81	2.46	2.35	51.
Seven Mile....	128	3.46	1.89	1.57	55.	3.98	0.74	3.24	19.	4.50	3.04	1.46	68.	4.65	3.57	1.08	77.
Four Mile.....	178	3.85	2.01	1.84	52.	3.88	0.10	3.78	2.6	4.75	3.40	1.35	72.	4.78	3.61	1.17	75.
Hamilton.....	3672	2.71	0.80	1.91	30.	3.34	0.18	3.16	5.4	3.48	1.76	1.72	51.	4.70	2.82	1.88	60.

being caused by heavy runoff from the areas below Dayton. The streams then fell rapidly, reached normal stages by the 14th in all cases.

Dec. 24, 1915-Jan. 7, 1916

The flood of the last of December, 1915, and the first of January, 1916, was due to rain falling on a partially melted accumulation of snow. Precipitation occurred nearly every day during the period from December 24 to January 7. During the last of December the temperature at Dayton varied from a few degrees below the freezing point to a few degrees above, so that the precipitation was sometimes snow and sometimes rain. Above Dayton the temperatures were slightly lower. The result was that by the end of the month there was an accumulation of from 6 to 12 inches of snow above Dayton. This was melted by a rainfall of from one to one and a half inches falling on January 1 and 2.

Some flood runoff occurred during the last of December. However, the main part of the flood began on the morning of January 1. The highest stages were reached sometime during the 1st or 2nd, at all places except Hamilton. At this station the crest occurred early in the morning of the 3rd. The surface runoff had drained out completely by the 10th.

The rainfall during November and the first three weeks of December was not greatly different from normal; so that the ground was practically saturated when the storm began. As no cold waves had occurred up to that time the ground could not have contained any appreciable amount of frost.

January 10-13, 1916

The most intense precipitation during the storm of January 10-13, 1916, occurred on the 12th, although appreciable amounts fell on each of the other dates. On the 10th, the first day of the storm, the average rainfall over the different drainage areas varied from 0.15 inches in the Miami Valley above Piqua, to 0.37 inches in the Buck Creek Valley. On the 11th, the amounts were about the same except that they were slightly heavier below Dayton. On the 12th, the amounts varied from 0.51 inches in the Buck Creek Valley to 1.14 inches above Germantown. The following day, the last day of the storm, the rainfall was comparatively light below Dayton. However, above Dayton it varied

from an average of 0.06 inches in the Stillwater Valley to 0.54 inches in the Buck Creek Valley.

The precipitation occurred as rain on the 10th, 11th, and 12th, but changed to snow on the 13th, as the temperature fell with the passing of the storm.

The streams began rising on the 11th and reached their highest stages on the 13th. They then fell rapidly reaching normal stages by the 17th or 18th.

The weather and soil conditions during the last of December, 1915, and the first few days of January, 1916, are indicated by the description of the preceding storm. Comparatively low temperatures from January 6 to 8, inclusive, froze the ground to a depth of from three to five inches, as indicated by observations at Moraine Park. Consequently, the conditions were conducive to high rates of runoff.

January 26-31, 1916

The storm of January 26 to 31, 1916, followed close after the storm of January 10 to 13. The weather from the 13th to the 19th, inclusive, was cold with temperatures as low as 3 degrees below zero at Dayton. Consequently the soil, which had been saturated by the preceding storm, froze to a depth of several inches. The weather warmed up on the 20th, and from a quarter to a half an inch of rain fell each day on the 20th, 21st, and 22nd. From the 23rd to the 26th the weather was warm and fair.

Only a few hundredths of an inch fell on the 26th. On the 27th, 28th, and 29th, the precipitation over the different areas varied from 0.06 to 0.34 inches, from 0.18 to 0.45 inches, and from 0.38 to 0.69 inches, respectively. On the 30th and 31st the most intense precipitation occurred. The amounts varied from 0.67 inches above the Buck Creek station to 1.57 inches above West Milton, on the 30th; and from 0.41 inches above Springfield to 0.94 inches above Lockington, on the 31st.

The rivers began rising on the 28th, reached their highest stages on January 31 and February 1, and then fell rapidly reaching comparatively low stages by February 6 in all cases. The rate of falling was increased somewhat by the comparatively cold weather which followed the storm.

March 21-22, 1916

Practically all of the rainfall during the storm of March 21 to 22, 1916, fell on the 22nd, only a few hundredths of an inch

falling on the 21st. The soil was saturated due to the precipitation of the preceding part of the winter but was not frozen. Although some snow had fallen during the earlier part of the month, it had all melted by the 21st.

The rivers began rising on the 21st, reached their highest stages on the 22nd or 23rd, and then fell rather slowly. The flood runoff has been determined for the period beginning on the 21st and ending on the 26th. Flood runoff after the 26th was not included because the following storm began on the 25th. As there was still some surface runoff in the streams on the 26th, caused by the storm of the 21st and 22nd, the values given in the tables may be slightly low for this storm and slightly high for the following one.

March 25-28, 1916

Only a few hundredths of an inch fell on the 25th. On the 26th the average precipitation for the different drainage areas varied from 0.28 to 1.07 inches, the greater amounts falling in the lower portions of the valley. On the 27th the values varied from 0.35 to 1.81 inches, the greater amounts on this date falling on the Mad River drainage area. The precipitation on the 28th was comparatively small, the averages for the various basins varying from 0.04 to 0.24 inches.

The streams began rising again on the 26th, reached their highest stages on the 27th and 28th, and then fell rapidly. By April 3 the surface runoff had entirely passed the city of Hamilton, the lowest station included in the table.

May 6-7, 1916

The entire precipitation in this storm fell during the night of May 6 and 7. Although a few hundredths of an inch fell during the period from May 10 to 13, no surface runoff resulted and consequently the amounts have not been included in the table.

The ground was fairly wet when the rain began, due to the rains of April and of May 2, 3, and 4, but was not fully saturated. Evaporation and transpiration rates were considerably higher than they had been during the preceding months, but had not yet reached their maximum summer values.

The streams rose rapidly, reaching their crest stages on the 7th and 8th, and then fell rapidly. By the 13th the stage at Hamilton had fallen to a normal value.

January 3-6, 1917

The most intense precipitation during the storm of January 3 to 6, 1917, fell on the 5th and 6th. The rainfall on the 3rd and 4th was comparatively light, amounting to only a few hundredths of an inch each day. On the 5th and 6th the total amounts varied from 1.67 inches in the Miami Valley above Sidney and in the Buck Creek Valley above Springfield to 2.12 inches in the Twin Creek Valley above Germantown.

The soil was practically saturated when the rain began and was not frozen, although some freezing weather had occurred during the preceding month. There was no snow on the ground. The precipitation during the entire storm was in the form of rain.

The rivers began rising on the 5th, reached their highest stages on the 5th and 6th, and then fell steadily. The total flood runoff had passed Hamilton by the 10th.

March 11-14, 1917

The heaviest rainfall during the storm of March 11 to 14, 1917, fell on the 13th, the amounts on that day varying from 0.95 inches above the Wright, Seven Mile, and Four Mile stations, to 1.49 inches above Pleasant Hill. The rainfall averaged about a half an inch throughout the valley on the 11th, and from 0.05 to 0.37 inches on the 12th, the heaviest precipitation on the latter date falling in the southern part of the valley. On the 14th the rainfall varied from 0.07 inches in the Mad River Valley to 0.38 inches in the Seven Mile basin.

The ground was saturated when the rain began due to the precipitation of the preceding winter. The rainfall was greater than normal during January. Although the precipitation was less than normal during February the meteorological conditions were not such as to dry the ground to any appreciable depth. Some rain fell in the valley on each day of March preceding the storm except the 1st, 9th, and 10th.

The rivers began rising on the 11th, fell slightly on the 12th, and then began rising again on the 13th, reaching crest stages on the 13th and 14th. The flood runoff had passed Hamilton by the 20th.

Light rainfall occurred on the 16th, 17th, and 18th, but no surface runoff was caused and consequently the amounts have not been included in the table.

June 26-29, 1917

Only a few hundredths of an inch fell on June 26, the first day of the storm. On the 27th, the average precipitation on the different drainage areas varied from 0.48 inches above Lockington to 1.08 inches above Wright. On the 28th, the amounts varied from 0.63 inches above Germantown to 1.13 inches above Springfield. On the 29th, the rainfall varied from 0.03 inches in the Buck Creek Valley to 0.56 inches above Sidney and Tadmor.

The ground was in ordinary June condition, being neither unusually dry nor unusually wet. Although considerable precipitation had occurred during the preceding part of the month it had been utilized by the comparatively high evaporation and transpiration rates which occur during this part of the year.

The streams began rising on the 28th, reached their highest stages on the 28th and 29th, and then fell slowly. The total surface runoff had passed Hamilton by the 5th.

Although some precipitation occurred on July 2, no appreciable surface runoff resulted. Consequently the amounts have not been included in the table.

July 12-17, 1917

The storm of July 12 to 17, 1917, followed close after the preceding described storm. The rainfall on July 12 varied from 0.22 inches above Germantown to 0.88 inches above Sidney. On the 13th the amounts varied from 0.17 inches above Sidney to 0.47 inches above Pleasant Hill. On the 14th, the day of heaviest precipitation, the amounts varied from 0.65 inches in the Four Mile Creek Valley to 1.72 inches above Sidney. On the 15th the precipitation was comparatively light, the amounts being less than a quarter of an inch except in the upper Miami Valley where they varied from 0.29 inches above Tadmor to 0.39 inches above Lockington. The rainfall was light throughout the valley on the 16th. On the 17th, the last day of the storm, the amounts varied from 0.11 inches above Lockington to 1.17 inches in the Four Mile Creek basin. The ground was fairly wet when the rain began, due to previous rainfall, but was not saturated.

The rivers began rising on the 13th, reached their maximum stages on the 14th and 15th, and then fell slowly, The total flood runoff had passed Hamilton by the 22nd.

Dec. 28, 1917, to Feb. 15, 1918

The flood of February, 1918, was caused almost entirely by melting snow. The winter of 1917 and 1918 was noted for its

severity. The occurrence of heavy snows and severe cold waves began early in December. The greater part of the precipitation between December 3 and February 11 occurred as snow, the temperature being below freezing the greater part of the time, sometimes several degrees below zero.

The ground froze to a depth of a few inches during the cold period from December 6 to 18, but thawed out and became saturated during the warmer period from the 19th to the 27th. The snows of the early part of December melted during the latter period, the melting being hastened somewhat by light rainfall occurring on the 23rd, 24th, and 25th. The ground then froze again, due to colder weather, and remained frozen until the thawing period of February.

During the period from December 28 to January 3, inclusive, the snowfall throughout the valley was equivalent to about 0.65 inches of rain. This snow was partially melted by a rainfall of about an inch occurring during the period from the 5th to the 8th. Freezing weather began again, however, before much surface runoff could occur. From January 11 to February 6 the snowfall was equivalent to about 2 inches of rain. The actual amounts varied from 1.60 inches above Lockington to 2.58 inches above the Four Mile Creek station. From February 7 to 15 the precipitation amounted to about a half an inch throughout the valley. This was in the form of rain and was distributed over several days time.

Small rises occurred in January. However, the principal flood runoff began February 9. The streams rose rather irregularly reaching their highest stages on the 12th or 13th. Ice jams occurred in many places. The flood runoff had drained out by the 18th.

May 11-13, 1918

The most intense precipitation during the storm of May 11 to 13, 1918, fell on the 12th and 13th, less than a half an inch falling on the 11th. The soil was in ordinary May condition when the rain began. It was not saturated although the precipitation during the preceding month had been greater than normal.

The streams began rising on the 12th, and reached their highest stages on the 13th. They then fell rather uniformly, reaching normal stages by the 18th or 19th.

August 25-31, 1918

The precipitation during the storm of August 25 to 31 was heaviest in the Mad River Valley although heavy rainfall occurred throughout the Miami River drainage area. Only a few hundredths of an inch fell on the 25th. However, the rest of the precipitation was distributed rather uniformly throughout the remainder of the storm period.

The soil was neither unusually dry nor unusually wet when the rain began. The streams in the Mad River Valley began rising on the 30th and reached crest stages on the 30th or 31st. But little, if any, flood runoff occurred in the other portions of the valley. By September 3 the total surface runoff had passed Hamilton.

March 14-19, 1919

Although the precipitation during February and the first part of March had been less than normal, the ground was practically saturated when the storm of March 14 to 19, 1919, began. The precipitation on the 14th was comparatively light, amounting to only a few hundredths of an inch. The heaviest rainfall of the storm occurred on the 15th. The total precipitation on the 14th and 15th, up to 7 p.m., of the latter date, varied from 1.15 inches above Sidney to 2.47 inches above the Four Mile Creek station. On the following day the rainfall was not quite so intense, the amounts varying from 0.77 inches in the Buck Creek Valley to 1.54 inches in the Twin Creek Valley. On the 17th and 18th the rainfall was nearly uniform throughout the Miami Valley, the total amounting to about 0.75 inches on the 17th, and to about 0.25 inches on the 18th. Only a few hundreds of an inch fell on the 19th. The intensities at Moraine Park on the 15th, 16th, and 17th, are shown in figure 10, page 81.

The rivers began rising on the 15th, reached their crest stages on the 16th and 17th, and then fell uniformly, reaching normal stages in all parts of the valley by the 24th.

April 15-21, 1920

The storm of April 15 to 21, 1920, caused the highest stage that has occurred at Dayton since the great flood of March, 1913. Only a few hundredths of an inch fell on the 15th. On the 16th the precipitation was considerably heavier. The total amounts for the 15th and 16th varied from 0.83 inches in the

Seven Mile Valley to 1.92 inches above Sidney. Averages varying from 0.25 to 0.50 inches per day over the valley fell on the 17th, 18th, and 19th. On the 20th and 21st the precipitation was again heavy, the daily amounts varying from about a half an inch to about 2 inches in the different parts of the valley. The rainfall was slightly greater on the 20th than on the 21st except in the Mad River Valley.

The ground was nearly saturated when the rain began, due to rains of March and the early part of April.

The rivers began rising on the 16th, fell on the 17th, 18th, and 19th, and then rose rapidly on the 20th, reaching crest stages on the 20th and 21st. They then fell rapidly, reaching normal stages throughout the valley by the 28th.

TOTAL RETENTION

A study of the data in table 34 shows that during similar storms the total retention is generally greater in the Mad River drainage area than in the other portions of the Miami Valley. For instance, during the storm of December 24, 1915, to January 7, 1916, the total retention above Springfield, resulting from a precipitation of 3.65 inches, amounted to 2.70 inches; while in the Stillwater Valley above West Milton the retention, due to a precipitation of 3.99 inches, was only 1.00 inch. In the Miami Valley above Tadmor the retention caused by a precipitation of 3.89 inches amounted to 1.01 inches, or practically the same as in the Stillwater Valley. Other storms show similar conditions, although the differences are not always so great. The total retention in the Buck Creek Valley is generally a little greater than in the other parts of the Mad River drainage area.

As explained in chapter V, the relatively high retention in the Mad River Valley is due to the comparatively loose and shallow surface soil, underlain by extensive deposits of gravel.

The total retention during the summer storms seems to be much greater than during similar winter storms, as would, of course, be expected, due to the relatively higher rates of evaporation and soil absorption and the greater amounts of available surface and soil storage during the summer. This is well shown by a comparison of the storms of August 25 to 31, 1918, and April 15 to 21, 1920. These storms were very similar as regards duration and intensity. The total precipitation during the August storm was somewhat smaller than during the April storm, especially in the Stillwater and Upper Miami Valleys.

However, in spite of the smaller rainfall, the retention during the August storm was greater than during the September storm in every catchment area, the differences varying from 0.50 inches above Germantown to 2.61 inches above the Four Mile Creek station in all instances except Buck Creek. In this case the difference was only 0.05 inches.

The negative values of total retention obtained for the Seven Mile and Four Mile Creek valleys for the storms of January 10 to 13 and 26 to 31, 1916, are probably in error. This may be due to either or both of two causes. The runoff may be too large due to the difficulties encountered in securing accurate records on a flashy stream of this nature; or the rainfall may be too small due to the occurrence of heavy showers between rain gaging stations. It is believed that the latter reason accounts for the greater parts of the discrepancies. For similar reasons some of the data for the smaller drainage areas for other storms may be in error.

As before mentioned the total retention for a given storm period represents the total quantity of water taken up by the soil plus the total quantity evaporated. Rates of soil absorption and evaporation both vary widely due to variations in meteorological, topographical, and geological conditions. Consequently it does not seem feasible to estimate the value of each component during the various storms given in table 34.

Soil absorption and evaporation are both relatively high in the summer and relatively low in the winter. The former is probably greater if the rainfall is steady, than it is if the rain falls in separate intense showers. The latter is greater when the rain falls intermittently, especially if the showers are separated by intervals of warm windy weather. In the case of forested areas appreciable amounts of the precipitation are intercepted by the foliage of the trees and are evaporated after the rain ceases without ever having reached the ground.

While the areas covered by forests in the Miami Valley are relatively small some data on interception has been secured. During the summer and fall of 1919 two rain gages were maintained by the writer at his residence. One was located in the open and the other under a hackberry tree, about forty feet high, about midway between the trunk and the outer edge of the foliage. The data secured is given in full in table 35.

It will be noticed that the quantities intercepted vary considerably. During slow steady rains from 0.10 to 0.15 inches are

Table 35.—Rainfall Intercepted by Hackberry Trees at Dayton

Date	Rain		Precipitation in Open in Inches	Intercepted by Trees in Inches	Remarks
	Began	Ended			
7–31–19	4 a.m.	6 a.m.	0.43	0.12	Steady rain.
7–31–19	2 p.m.	2:15 p.m.	0.47	0	High wind.
8– 1–19	d.n.	d.n.	0.03	0.03	Steady rain.
8– 5–19	p.m.	6 p.m.	0.07	0.07	Steady rain.
8– 6–19	d.n.	d.n.	0.12	0.03	Steady rain.
8–13–19	p.m.	d.n.	0.25	0.14	Light showers.
8–16–19	11:25 a.m.	11:40 a.m.	0.80	0	Strong wind, some hail.
8–24–19	5 p.m.	6 p.m.	0.15	0.10	Steady rain.
8–24–19	7 p.m.	9 p.m.	0.95	0.02	Thunder-showers.
8–31–19	5 p.m.	8 p.m.	0.21	0.10	Showers.
9–19–19	d.n.	8 a.m.	0.14	0.07	Showers with some wind.
9–21–19	d.n.	d.n.	0.77	0.17	Showers with some wind.
9–21–19	3 p.m.	6 p.m.	0.42	0.15	Showers, clear and windy during forenoon.
*10– 4–19	5 p.m.	d.n.	0.49	0.26	Light showers, windy between showers.
10– 5–19	noon	d.n.	1.02	0.20	Heavy showers, some wind.
10– 9–19	d.n.	7:30 a.m.	0.35	0.12	Steady rain, no wind.
10– 9–19	7:30 a.m.	9 a.m.	0.13	0.02	Steady rain, no wind.
10–10–19	10 a.m.	d.n.	0.83	0.43	Showers, clear between.
10–14–19	d.n.	7:30 a.m.	0.16	0.07	Steady rain.
10–15–19	d.n.	7:30 a.m.	0.25	0.07	Light showers.
10–21–19	d.n.	noon	0.21	0.11	Showers.
10–25–19	d.n.	7:30 a.m.	0.06	0.04	Light showers.
10–26–19	d.n.	5 p.m.	0.62	0.26	Showers.
10–27–19	d.n.	6:30 a.m.	0.43	0.22	Showers.
10–29–19	noon	6 p.m.	0.27	0.14	Showers.
10–31–19	5:30 a.m.	7 a.m.	0.20	0.12	Showers.
10–31–19	7 a.m.	6 p.m.	0.92	0.24	Showers.
11– 7–19	d.n.	7 a.m.	0.51	0.11	Steady rain.
11–10–19	8 a.m.	6 p.m.	0.42	0.11	Showers.
5–23–20	6 p.m.	6:30 p.m.	0.62	0.16	Thunder-showers, some wind.
6– 2–20	6:35 p.m.	7:10 p.m.	1.25	0.15	Strong wind for about 10 minutes, some hail.
6– 9–20	8 p.m.	9 p.m.	0.34	0.19	Steady rain.
6–14–20	d.n.	d.n.	0.38	0.23	Showers, warm and windy between showers.

*Leaves began falling late in September, nearly all gone by end of October.

intercepted. If the precipitation occurs as showers, separated by clear, windy intervals, the quantities intercepted are considerably higher, due to the evaporation between showers.

MAXIMUM VALUES OF RETENTION

Table 36 gives the maximum values of retention, in inches, during a few of the larger storms. The quantities were obtained from mass curves of rainfall and runoff similar to those shown in figure 46. They are not as definitely determined as they would have been if data on hourly rainfall had been available. Except in a few instances the rainfall data was limited to daily amounts. Had more exact information been at hand the values of maximum retention would probably have been increased slightly.

Table 36.—Maximum Retention, in Inches, During Various Floods

Gaging Station	Dates of Storms					
	July 7–8 1915	January 10–13 1916	January 26–31 1916	March 21–22 1916	March 25–28 1916	March 14–19 1919
Sidney	1.94	1.20	1.41	1.15	1.17	2.13
Lockington	....	1.03	1.30	0.71	0.60	1.63
Piqua	2.04	1.12	1.58	1.07	1.13	1.91
Tadmor	2.08	1.30	1.91	1.13	1.31	2.30
Pleasant Hill	....	....	....	....	....	1.81
West Milton	2.88	1.50	1.89	0.65	1.01	1.59
Buck Creek	1.95	1.15	1.42	0.79	1.51	2.50
Springfield	2.02	1.25	1.38	0.92	1.64	2.24
Wright	2.09	1.28	1.66	0.87	1.80	2.29
Dayton	2.28	1.36	1.93	0.94	1.46	2.26
Franklin	....	....	....	0.96	1.47	2.33
Germantown	2.96	1.38	1.51	*	1.36	2.19
Seven Mile	2.53	0.97	0.64	*	1.24	2.55
Four Mile	2.16	0.59	0.96	*	1.34	2.49
Hamilton	2.32	1.40	1.87	0.78	1.43	2.45

*No flood runoff.

The maximum retention occurred sometime prior to the occurrence of the crest stages. In the case of the July, 1915, storm they occurred about the time the rain ceased. Since practically the entire rainfall fell in about an hour in this instance, the maximum values of retention are nearly as great as the total precipitation. Other conditions being the same the values tend to be lower on the smaller drainage areas due to the comparatively short time required for the runoff to reach the gaging sections.

The maximum value of retention, being the maximum difference between the mass curves of rainfall and runoff, repre-

sents the accumulated soil absorption plus the accumulated evaporation plus the actual quantity of water held on the ground or in the streams at the time the maximum retention occurs. The accumulated soil absorption plus the accumulated evaporation cannot be definitely determined except for the entire flood period. However, it is possible, by a proper consideration of the duration of the storm and of the time of occurrence of the maximum retention, to estimate the proportion of the total absorption and evaporation which has occurred up to the time of the maximum retention. These estimated quantities may then be deducted from the values of maximum retention, thus obtaining estimated values of the maximum quantities stored on the ground surface and in the streams.

Table 37 gives the estimated values of accumulated soil absorption and evaporation at the time of the maximum retention, and also the resulting estimates of maximum surface storage, for the storms included in table 36.

The volumes of water stored in the channels of the streams may be directly calculated whenever data is available regarding water levels, area of cross sections, and distances. Table 38 gives the maximum volumes stored in certain lengths of the principal streams of the Miami Valley during the floods of July, 1917, March, 1919, and March, 1913, calculated in this manner.

The flood of July, 1917, was a comparatively small freshet. not exceeding the channel capacity at any place in the valley. The maximum rates of discharge were only from 5 to 8 per cent of the maximum rates which occurred during the 1913 flood. The flood of March, 1919, was somewhat larger. It caused some overflow in practically all parts of the valley outside the cities. The maximum rates of discharge in this case were from 10 to 20 per cent of the maximum 1913 rates.

The volumes given for the March, 1919, flood do not include the storage on the overflowed lands outside of the main channels. However, the volumes given for the March, 1913, flood do include such storage. In the latter instance the volumes on the overflowed areas were much larger than the volumes within the channels themselves.

Reference to table 38 shows that the quantities held in the main channels during the floods of July, 1917, and March, 1919, were relatively small. Since these quantities represent the storage in the channels when the crest stages occurred, the quantities in the channels when the maximum surface storage took place

Table 37.—Soil Absorption, Evaporation, and Maximum Surface Storage during Various Floods

Gaging Stations	Total Soil Absorption and Evaporation up to Time of Maximum Retention — Floods of						Maximum Surface Storage — Floods of					
	July 7-8, 1915	January 10-13, 1916	January 26-31, 1916	March 21-22, 1916	March 25-28, 1916	March 14-19, 1919	July 7-8, 1915	January 10-13, 1916	January 26-31, 1916	March 21-22, 1916	March 25-28, 1916	March 14-19, 1919
Sidney	1.29	0.50	0.30	0.52	0.25	1.01	0.65	0.70	1.11	0.63	0.92	1.12
Lockington	......	0.10	0.25	0.14	0.22	0.70	......	0.93	1.05	0.57	0.38	0.93
Piqua	0.89	0.35	0.42	0.40	0.20	0.73	1.15	0.77	1.16	0.67	0.93	1.18
Tadmor	1.25	0.50	0.54	0.44	0.29	1.00	0.83	0.80	1.37	0.69	1.02	1.30
Pleasant Hill	......	......	......	......	......	0.52	......	......	......	......	......	1.29
West Milton	1.49	0.70	0.13	0.35	0.37	0.37	1.39	0.80	1.76	0.30	0.64	1.22
Buck Creek	1.74	0.83	1.07	0.71	0.90	1.52	0.21	0.32	0.35	0.08	0.61	0.98
Springfield	1.63	0.85	0.95	0.84	0.96	1.46	0.39	0.40	0.43	0.08	0.68	0.78
Wright	1.58	0.77	1.07	0.59	0.87	1.41	0.51	0.51	0.59	0.28	0.93	0.88
Dayton	1.49	0.53	0.61	0.45	0.38	0.71	0.79	0.83	1.32	0.49	1.08	1.55
Franklin	......	......	......	0.45	0.34	0.90	......	......	......	0.51	1.13	1.43
Germantown	1.58	0.48	0.63	0.43	0.80	1.28	1.38	0.90	0.88	......	0.56	0.91
Seven Mile	1.43	0.04	......	0.19	0.77	1.10	1.10	0.93	......	......	0.47	1.45
Four Mile	0.70	......	......	0.18	0.83	1.01	1.46	......	......	......	0.51	1.48
Hamilton	1.57	0.54	0.63	0.41	0.47	1.29	0.75	0.86	1.24	0.37	0.96	1.16

must have been still smaller. A study of the data in table 37 and 38 shows that the greater parts of the maximum surface storage during the floods included in table 37 must have been on the ground, in the small pools and depressions, and in the channels of the smaller tributary streams, rather than in the main channels.

RATES OF RAINFALL AND RUNOFF

Table 39 gives the maximum daily rates of rainfall and runoff in inches over the drainage areas, and the absolute maximum rate of runoff, in inches per 24 hours, for the greater number of the storms included in table 34. The greatest 24-hour runoff is not the maximum amount calculated for the 24 hours ending at 7 p.m., but is the amount for the 24 hours in which the greatest runoff occurred. It was obtained graphi-

Table 38.—Storage in River Channels During Various Floods

River	Length	Drainage Area* Square Miles	Storage in Inches Flood of		
			July 1917	March 1919	March 1913
Stillwater	Pleasant Hill to Dayton	674	0.16	0.33	1.48
Miami	Loramie Creek to Dayton	1162	0.17	0.21	1.64
Mad	Springfield to Dayton	689	0.07	0.09	1.79
Miami	Dayton to Hamilton	3672	0.14	0.22	1.19
Total of 3 lengths above Dayton		2525	0.14	0.21	1.64
Total of 4 lengths above Hamilton		3672	0.24	0.36	2 31

*Total above lower end of length.

cally after the hydrographs had been platted. However, the maximum 24-hour rainfall is the maximum for the 24 hours ending at 7 a.m. or 7 p.m., generally the latter, rather than the actual maximum. The available rainfall data was not sufficient to determine the true 24-hour maximum. The ratio of the greatest daily runoff to the greatest daily rainfall, in per cent, is also included.

It will be noticed that no very unusual 24-hour rainfalls have ocurred during the period covered by the table. With the exception of the summer storms of July, 1915, and May, 1916, the quantities seldom amount to as much as two inches. The runoff during the summer storms was relatively less than during the winter storms as already mentioned. Consequently the

Table 39.—Rates of Rainfall and Runoff During Various Storms

Gaging Station	Drainage Area Square Miles	Storm of July 7–8, 1915				Storm of January 10–13, 1916				Storm of January 26–31, 1916				Storm of March 21–22, 1916			
		Maximum 24-hour Rainfall in Inches	Maximum 24-hour Runoff in Inches	Ratio of Maximum Runoff to Maximum Rainfall in per cent	Maximum Rate of Runoff in Inches per 24 Hours	Maximum 24-hour Rainfall in Inches	Maximum 24-hour Runoff in Inches	Ratio of Maximum Runoff to Maximum Rainfall in per cent	Maximum Rate of Runoff in Inches per 24 Hours	Maximum 24-hour Rainfall in Inches	Maximum 24-hour Runoff in Inches	Ratio of Maximum Runoff to Maximum Rainfall in per cent	Maximum Rate of Runoff in Inches per 24 Hours	Maximum 24-hour Rainfall in Inches	Maximum 24-hour Runoff in Inches	Ratio of Maximum Runoff to Maximum Rainfall in per cent	Maximum Rate of Runoff in Inches per 24 Hours
Sidney	555	1.94	0.27	14.	0.32	1.08	0.34	31.	0.38	1.08	0.76	70.	0.82	1.48	0.38	26.	0.40
Lockington	255	Gage	install	ed 9-1	3–1916	0.98	0.39	40.	0.47	1.37	1.18	86.	1.46	1.13	0.35	31.	0.57
Piqua	842	2.05	0.47	23.	0.58	1.04	0.38	37.	0.43	1.18	0.79	67.	0.91	1.37	0.35	26.	0.42
Tadmor	1128	2.10	0.37	18.	0.46	1.00	0.35	35.	0.39	1.14	0.79	69.	0.89	1.25	0.28	22.	0.31
Pleasant Hill	453	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
West Milton	600	2.89	0.63	22.	0.69	1.02	0.33	32.	0.39	1.57	1.06	68.	1.49	0.84	0.22	26.	0.23
Buck Creek	163	1.95	0.14	7.	0.16	0.83	0.32	39.	0.34	0.67	0.32	48.	0.36	1.04	0.25	24.	0.32
Springfield	488	2.04	0.32	16.	0.37	0.91	0.40	44.	0.47	0.83	0.33	40.	0.40	1.19	0.27	23.	0.33
Wright	652	2.09	0.26	12.	0.31	0.91	0.37	41.	0.43	0.78	0.31	40.	0.34	1.04	0.23	22.	0.26
Dayton	2525	2.30	0.37	16.	0.41	0.99	0.40	40.	0.45	1.13	0.69	61.	0.75	1.04	0.25	24.	0.27
Franklin	2785	.....	.....	.....	.....	.....	.....	.....	.....	Gage	install	ed 3–1	5–1916	0.99	0.23	23.	0.25
Germantown	272	2.99	1.00	33.	1.61	1.14	0.75	66.	0.98	1.38	0.95	69.	1.23	0.43	No F	lood R	unoff
Seven Mile	128	2.53	0.78	31.	1.80	0.97	0.93	96.	1.37	1.20	1.42	118.	2.41	0.19	No F	lood R	unoff
Four Mile	178	2.16	0.54	25.	0.75	0.84	1.10	131.	1.84	1.22	1.36	111.	1.84	0.18	No F	lood R	unoff
Hamilton	3672	2.32	0.28	12.	0.29	1.04	0.39	37.	0.43	1.08	0.55	51.	0.57	0.82	0.16	20.	0.17

Table 39.—*Continued*

Gaging Station	Drainage Area Square Miles	Storm of March 25–28, 1916				Storm of May 6–7, 1916				Storm of January 3–6, 1917				Storm of March 11–14, 1917			
		Maximum 24-hour Rainfall in Inches	Maximum 24-hour Runoff in Inches	Ratio of Maximum Runoff to Maximum Rainfall in per cent	Maximum Rate of Runoff in Inches per 24 Hours	Maximum 24-hour Rainfall in Inches	Maximum 24-hour Runoff in Inches	Ratio of Maximum Runoff to Maximum Rainfall in per cent	Maximum Rate of Runoff in Inches per 24 Hours	Maximum 24-hour Rainfall in Inches	Maximum 24-hour Runoff in Inches	Ratio of Maximum Runoff to Maximum Rainfall in per cent	Maximum Rate of Runoff in Inches per 24 Hours	Maximum 24-hour Rainfall in Inches	Maximum 24-hour Runoff in Inches	Ratio of Maximum Runoff to Maximum Rainfall in per cent	Maximum Rate of Runoff in Inches per 24 Hours
Sidney........	555	1.50	0.60	40.	0.65	1.91	0.57	30.	0.72	1.67	0.17	10.	0.23	1.14	0.34	30.	0.37
Lockington....	255	1.01	0.58	57.	0.85	2.24	1.24	55.	2.06	1.92	0.50	26.	0.71	1.36	0.67	49.	0.95
Piqua........	842	1.34	0.54	40.	0.58	2.03	0.71	35.	1.01	1.75	0.29	17.	0.35	1.22	0.44	36.	0.51
Tadmor.......	1128	1.39	0.50	36.	0.55	2.00	0.52	26.	0.67	1.82	0.26	14.	0.32	1.20	0.41	34.	0.50
Pleasant Hill...	453	Gage	install	ed 4–7	–1916	1.53	0.50	33.	0.57	2.01	0.34	17.	0.36	1.49	0.56	38.	0.59
West Milton...	600	1.00	0.40	40.	0.43	1.58	0.40	25.	0.48	2.02	0.32	16.	0.34	1.42	0.52	37.	0.53
Buck Creek....	163	1.75	0.41	23.	0.68	2.59	Small	Rise	Only	1.67	0.30	18.	0.41	1.00	0.23	23.	0.36
Springfield.....	488	1.79	0.49	27.	0.61	2.52	0.42	17.	0.57	1.80	0.27	15.	0.33	1 02	0.30	29.	0.37
Wright........	652	1.81	0.46	25.	0.51	2.37	0.35	15.	0.43	1.81	0.25	14.	0.28	0.95	0.28	29.	0.31
Dayton.......	2525	1.32	0.47	36.	0.52	1.97	0.43	22.	0.51	1.87	0.29	16.	0.32	1.20	0.41	34.	0.44
Franklin......	2785	1.26	0.47	37.	0.50	1.90	0.41	22.	0.46	1.88	0.26	14.	0.28	1.19	0.39	33.	0 41
Germantown...	272	1.00	0.44	44.	0.51	1.15	0.17	15.	0.29	2.12	0.61	29.	0.75	1.56	0.71	46.	0.96
Seven Mile...	128	1.07	0.41	38.	0 47	0.72	0.14	19.	0.26	1.69	0.73	43.	0.90	0.95	Recor	ds mis	sing
Four Mile.....	178	1.05	0.29	28.	0.33	0.71	0.10	14.	0.15	1.84	0.52	28.	0.82	......	0.73	......	2.93
Hamilton......	3672	1.06	0.33	31.	0.34	1.66	0.24	14.	0.25	1.92	0.27	14.	0.31	1.17	0.35	30.	0.37

Table 39.—*Continued*

Gaging Station	Drainage Area Square Miles	Storm of June 26–29, 1917: Maximum 24-hour Rainfall in Inches	Storm of June 26–29, 1917: Maximum 24-hour Runoff in Inches	Storm of June 26–29, 1917: Ratio of Maximum Runoff to Maximum Rainfall in per cent	Storm of June 26–29, 1917: Maximum Rate of Runoff in Inches per 24 Hours	Storm of July 12–17, 1917: Maximum 24-hour Rainfall in Inches	Storm of July 12–17, 1917: Maximum 24-hour Runoff in Inches	Storm of July 12–17, 1917: Ratio of Maximum Runoff to Maximum Rainfall in per cent	Storm of July 12–17, 1917: Maximum Rate of Runoff in Inches per 24 Hours	Storm of March 14–19, 1919: Maximum 24-hour Rainfall in Inches	Storm of March 14–19, 1919: Maximum 24-hour Runoff in Inches	Storm of March 14–19, 1919: Ratio of Maximum Runoff to Maximum Rainfall in per cent	Storm of March 14–19, 1919: Maximum Rate of Runoff in Inches per 24 Hours	Storm of April 15–21, 1920: Maximum 24-hour Rainfall in Inches	Storm of April 15–21, 1920: Maximum 24-hour Runoff in Inches	Storm of April 15–21, 1920: Ratio of Maximum Runoff to Maximum Rainfall in per cent	Storm of April 15–21, 1920: Maximum Rate of Runoff in Inches per 24 Hours
Sidney	555	1.15	0.13	11.	0.17	1.72	0.30	17.	0.36	1.15	0.45	39.	0.48	1.17	0.82	70.	0.90
Lockington	255	1.10	0.31	28.	0.36	1.60	0.47	29.	0.66	1.33	0.73	55.	0.90	1.08	1.20	111.	1.72
Piqua	842	1.16	0.21	18.	0.24	1.70	0.40	24.	0.50	1.21	0.56	46.	0.61	1.01	0.82	81.	0.91
Tadmor	1128	1.30	0.20	15.	0.23	1.57	0.28	18.	0.31	1.25	0.44	35.	0.47	1.08	0.90	83.	0.99
Pleasant Hill	453	0.98	0.34	35.	0.45	1.40	0.44	31.	0.50	1.58	0.76	48.	0.81	1.40	0.85	61.	0.89
West Milton	600	0.88	0.26	30.	0.34	1.28	0.35	27.	0.37	1.59	0.94	59.	1.00	1.44	0.97	68.	1.02
Buck Creek	163	1.08	No Flood Runoff			1.25	0.21	17.	0.23	1.24	0.23	19.	0.32	1.55	0.78	50.	0.96
Springfield	488	1.27	0.15	12.	0.18	1.66	0.27	16.	0.34	1.23	0.34	28.	0.40	1.52	0.77	51.	0.89
Wright	652	1.20	0.15	12.	0.18	1.38	0.18	13.	0.20	1.21	0.36	30.	0.39	1.50	0.71	48.	0.95
Dayton	2525	1.14	0.18	16.	0.19	1.41	0.25	18.	0.27	1.34	0.60	45.	0.64	1.27	0.83	65.	0.87
Franklin	2785	1.10	0.17	15.	0.19	1.37	0.24	18.	0.26	1.37	0.52	38.	0.54	1.33	0.67	51.	0.69
Germantown	272	0.63	No Flood Runoff			0.90	0.10	11.	0.14	1.65	0.91	55.	1.16	1.91	1.18	62.	1.38
Seven Mile	128	0.88	No Flood Runoff			......	0.49	......	1.28	2.12	1.16	55.	1.54	1.91	1.98	104.	3.96
Four Mile	178	0.95	No Flood Runoff			0.65	Data not computed			2.47	1.40	57.	1.86	1.93	1.72	89.	2.37
Hamilton	3672	0.98	0.11	11.	0.12	1.22	0.17	14.	0.18	1.48	0.49	33.	0.50	1.46	0.59	41.	0.60

Table 40.—Ratio of Maximum 24 Hour Discharge to Absolute Maximum Discharge, in Per Cent

Gaging Stations	Drainage Area Square Miles	DATES OF STORMS														
		July 7-8, 1915	December 24, 1916 Jan-7, 1916	January 10-13, 1916	January 26-31, 1916	March 21-22, 1916	March 26-28, 1916	May 6-7, 1916	January 3-6, 1917	March 11-14, 1917	June 26-29, 1917	July 12-17, 1917	May 11-13, 1918	August 25-31, 1918	March 14-19, 1919	April 16-21, 1920
Sidney	555	85	92	89	93	95	93	79	76	93	80	81	87	*	93	91
Lockington	255	...	76	83	81	62	69	60	69	72	84	71	92	*	81	69
Piqua	842	80	87	90	86	84	93	70	81	86	87	79	90	*	91	90
Tadmor	1128	79	87	89	88	89	89	78	81	83	86	91	96	83	96	91
Pleasant Hill	453	...	...	...	...	...	...	87	93	94	76	89	97	*	95	96
West Milton	600	92	90	84	71	97	91	83	93	98	76	93	95	*	94	96
Buck Creek	163	86	71	93	87	78	60	*	72	63	*	90	68	50	71	81
Springfield	488	88	81	87	80	81	80	73	84	81	83	80	72	74	85	87
Wright	652	84	93	85	92	87	91	81	90	91	81	88	88	92	93	75
Dayton	2525	90	93	90	92	92	91	84	90	93	94	92	92	85	96	95
Franklin	2785	...	...	...	...	92	93	88	92	95	91	91	94	89	97	97
Germantown	272	62	72	76	78	*	86	57	82	74	*	70	72	67	79	85
Seven Mile	128	44	88	68	59	*	87	56	81	**	*	39	52	90	75	50
Four Mile	178	72	95	60	74	*	88	71	64	25	*	*	56	*	75	72
Hamilton	3672	96	98	90	95	97	97	96	86	92	91	94	93	91	97	97

*No appreciable rise. **Records not obtained.

values of the 24-hour runoff are not unusually large. On the larger drainage areas they do not materially exceed an inch. On the smaller areas they seldom amount to more than an inch and a half. The ratios of the 24-hour runoff to the 24-hour rainfall, of course, vary widely, owing to the different characteristics of the storms as well as to the different soil and surface conditions.

The maximum rates of runoff in inches per day are, of course, somewhat larger than the average rates for the 24-hour periods. On the larger areas they sometimes amount to about an inch and a half. On the smaller areas they occasionally amount to from three to four inches.

Table 40 gives the ratios, in per cent, of the maximum 24-hour rates of discharge to the absolute maximum rates, for various floods. In order to conform with the arrangement in table 34, the storm dates have been given rather than the flood dates. Data for the flood of February, 1918, which was caused by melting snow, has not been included since the hydrographs were very erratic due to ice jams.

The values for a given station vary considerably, as would be expected, due principally to the different durations of the most intense precipitation. For the storms where practically the entire precipitation fell in one day, such as those of July 7 to 8, 1915, and May 6 to 7, 1916, the values are generally smaller than where the heavy rainfall continued through two or more days, as in the storms of January 26 to 31, 1916, and March 14 to 19, 1919. The values are, of course, generally smaller for the smaller drainage areas.

CHAPTER VIII.—FLOOD FORECASTING

One of the outgrowths of the rainfall and runoff investigations described in the preceding chapters has been the development of the flood forecasting system now maintained by the Miami Conservancy District. Steps toward the inauguration of this system were taken during the summer of 1916, following the freshets of January, February, March, and May of that year. It was recognized then that such a system would be a necessity during the coming construction period, and that the preliminary steps should be taken at once in order that by the time construction began a thoroughly established information service might be available to the contractors as one of the assets of the job.

Although the United States Weather Bureau was maintaining a flood warning service in the Miami Valley at that time, which it had inaugurated several years before, their forecasts were limited to rises in which flood stages were reached or exceeded. Such a service was, of course, wholly inadequate for the purposes of the District. Inasmuch as it would be necessary to locate the construction equipment to a considerable extent in the valleys along the river channels, or actually within the channels, where sudden rises of only two or three feet might cause considerable damage, it was felt that an independent system should be developed by which the necessary forecasts could be made and issued without the interposition of a third party at critical times. The necessity of adopting such a course became still more evident when it was considered that in several instances the construction work would be located at places where only four to six hours elapse between the occurrence of the most intense rainfall and the maximum stages.

It should be stated here that the most hearty cooperation has always existed between the officials of the Weather Bureau and of the Conservancy District and that this cooperation has resulted in a considerable saving in expense to both parties. Moreover, the agreement and accuracy of the forecasts issued from the two sources during critical times has resulted in a feeling of

confidence and security on the part of the people throughout the entire valley.

THE PRESENT SERVICE

At the present time forecasts of crest stages and the times of their occurrence are being made for the five dams and for all of the principal cities along the Miami River below Sidney. In the case of the dams and of the cities where construction work is being carried on in the river channels, forecasts are made for rises of all magnitude, even as small as one or two feet. For the other places forecasts are made only when the rises are great enough to cause some damage or to cause apprehension on the part of the public. However, complete information regarding river conditions is always available at the headquarters office for all places, even though the magnitude of the rise is negligible.

Warnings are issued to the construction engineers or contractors at the various places, or to other interested parties. During critical times bulletins regarding river conditions are issued to the public through the local newspapers or by posting in conspicuous places. Information is also widely distributed by telephone. Operators are kept on duty during the entire night so as to furnish desired information at any time. During one freshet two operators were kept busy answering such inquiries from early morning until midnight. These inquiries come not only from the residents of Dayton but also from residents of practically all parts of the valley, from Sidney on the north to the Ohio River on the south.

During long continued storms it is necessary to issue several forecasts. Final estimates of maximum stages to be attained cannot be made until the most intense precipitation has occurred and the weather conditions are such that no additional heavy rainfall is expected. At such times the preliminary forecasts are based on the total rainfall occurring up to the time the forecasts are made. These are issued with the information that the rain is expected to continue and that the forecasted stages will be exceeded by amounts depending on the amount of the subsequent rainfall. For weather forecasts the officials of the District rely entirely o nthe work of the U. S. Weather Bureau.

REPORTS BEING SECURED

In order to maintain the above described service it is, of course, necessary to receive numerous reports from all parts of the valley. Cooperative arrangements were made with the U. S. Weather Bureau in June, 1916, by which special rainfall and river reports from their observers are secured at the headquarters office of the District during storm periods, as well as at the local office of the Weather Bureau. Special reports at such times are also secured from the greater number of the stations maintained by the Miami Conservancy District. These reports are made by telephone or telegraph whenever 0.70 of an inch of rain falls in 24 hours or less, or whenever there is a sudden rise of three or more feet in the river stage. A confirmation of each report is made by mail as soon as the message has been telegraphed or telephoned.

The gaging stations in the Miami Valley are shown in figure 1, page 17. Reports are received from all of the combined river and rainfall stations, from all but one or two of the rainfall stations, and from nearly all of the river stations located above Hamilton. While it may appear to the reader at first that reports from so many stations are not necessary, it must be remembered that reports from all stations at the proper time cannot be expected. Observers have other work to do besides attending to their gages. Although the importance of making the reports should be emphasized to the observers, and although the members of the observers' families should be trained to take readings and send reports, it frequently happens that for some legitimate reason the report is not made. Such occurrences must be expected in a flood forecasting system and must be allowed for by arranging for more reports than are absolutely necessary. Too many reports do no harm while too few result in poor predictions.

Although the observers are permitted to send these reports by either telegraph or telephone, they are instructed to send them by telephone whenever it is feasible to do so. The advantages of receiving the messages by telephone are, first, that the forecaster can question the observers regarding existing rainfall, river, or weather conditions, thus obtaining desired information which they might otherwise neglect to furnish even though instructed previously to do so; and, second, that the observers, in reporting by telephone, are necessarily kept on the job until the message is delivered, thus insuring more prompt

delivery. Quite frequently it has happened that reports handed to telegraph operators in small towns have been delayed so long in transmission that they arrived too late to be of use.

One factor which has been of great assistance in the forecasting work of the District and which has made possible the forecasting of small rises of one or two feet in the principal streams, is the direct telephone communication maintained between the headquarters office and the division offices at the five dams. Private wires are maintained to each dam. Consequently it is posible to obtain accurate information from trained observers, directly interested in the work, at any time, without the trouble involved in putting through long distance calls by the usual methods.

The river observers are instructed to report the latest gage reading and time of observation; the time the rise began and the stage at that time; whether the river is rising, stationary, or falling; the maximum stage and time of occurrence, if the river is falling; and such general information regarding rainfall, snowfall, runoff, and weather as they may possess. Rainfall observers are instructed to report the time of beginning of rain; the time of reading the gage and the amount of the precipitation up to that time; whether or not it is still raining; the time of ending of the rain, if it has ended; the amount and character of the precipitation during the preceding week; and such general information regarding the nature of the rainfall, snowfall, runoff, and weather, as they may have observed.

FORECASTING METHODS

Owing to the comparatively short intervals of time required for the flood runoff to reach the main streams, flood forecasting in the Miami Valley is of necessity largely based on the forecaster's judgment and on his familiarity with previous floods. With reports coming in from all parts of the valley and with people clamoring for information simultaneously, there is no opportunity to sit down and quietly analyze the problem or to apply theoretical formulas.

The forecaster keeps in touch with the weather and soil conditions throughout the valley at all times so that when the rain begins he knows approximately how much precipitation will be required to fill the surface storage and what proportion of the remainder may be expected to be taken up by the soil. This information in conjuction with the rainfall reports and his knowl-

edge of similar previous floods enables him to forecast the maximum stages and the times at which they will be reached at the principal stations in the upper portions of the valley as soon as the most intense precipitation has ceased. Preliminary forecasts are, of course, made as the reports arrive, as previously noted, but maximum stages can not be forecasted until the most

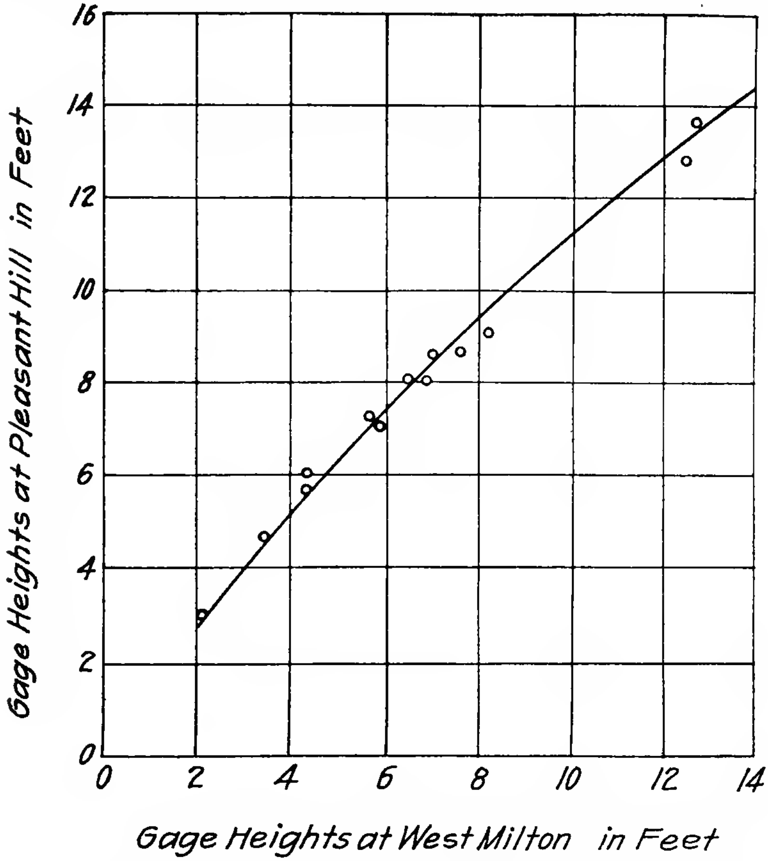

FIG. 47.—RELATION BETWEEN CREST STAGES ON THE STILLWATER RIVER AT PLEASANT HILL AND WEST MILTON.

intense precipitation has occurred. Having estimated the maximum stages to be attained in the upper portions of the valley, crest stages at the lower stations on the main streams above Dayton are forecasted by the aid of crest relation diagrams, proper consideration being given to channel storage and rainfall intensities below the upper stations.

Figure 47 shows the relation between crest stages at the

Pleasant Hill and West Milton stations on the Stillwater River; figure 48 shows a similar relation for the Springfield and Wright stations on Mad River; and figure 49 shows similar relations for the Sidney, Piqua, and Tadmor stations on the upper Miami River. Points vary from the curves somewhat in all instances, due to local variations in rainfall intensity. This is especially noticeable in the case of the Piqua-Tadmor curve, given in figure 49. Points falling to the left of the curve represent storms in which the most intense precipitation occurred

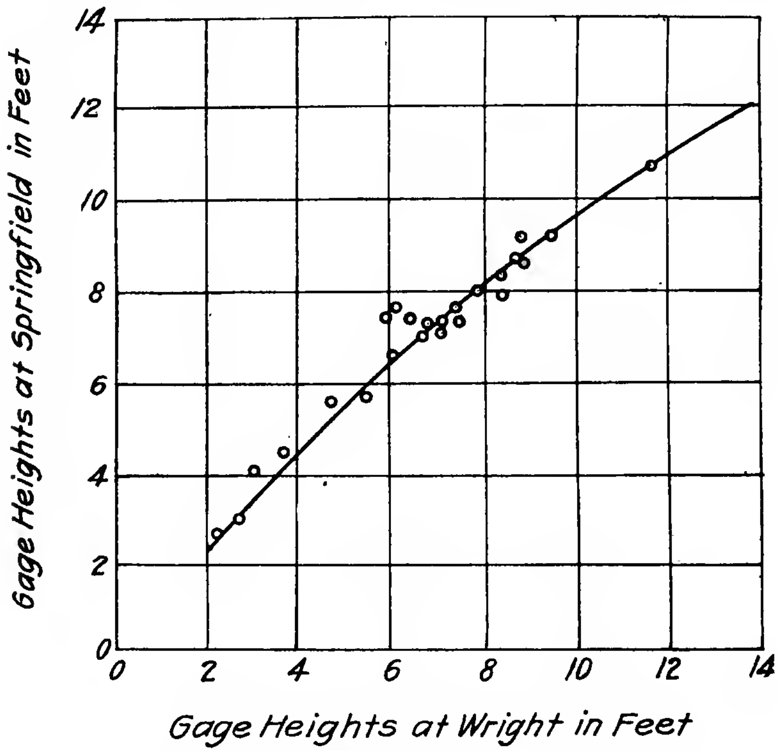

FIG. 48.—RELATION BETWEEN CREST STAGES ON THE MAD RIVER AT SPRINGFIELD AND WRIGHT.

over the northwestern portion of the drainage area; while points falling to the right represent storms where the heavy rain fell mostly on the eastern portions of the valley. Discrepancies due to this cause are less noticeable on the Sidney-Tadmor curve because heavy rainfall falling east of Piqua drains northward toward Sidney as well as southward toward Tadmor, thus producing similar conditions at both places. It is for this reason

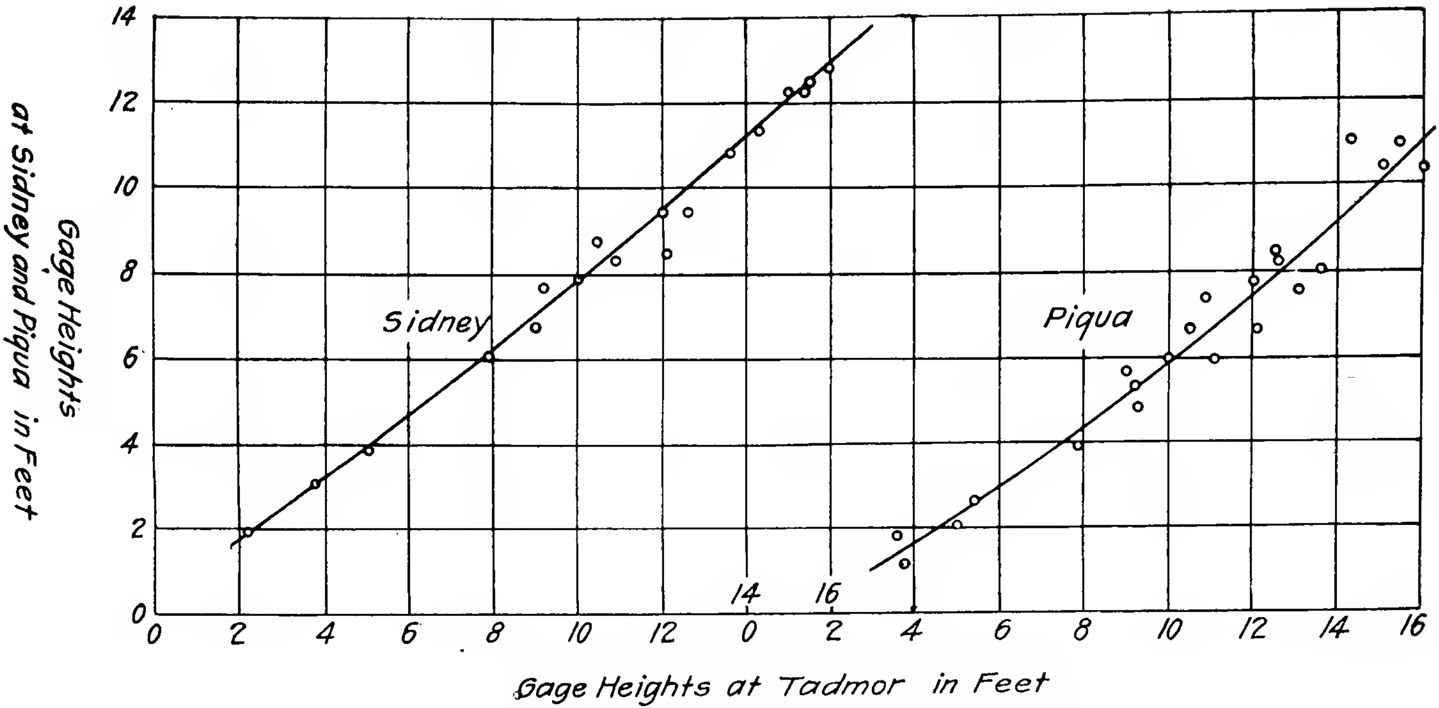

FIG. 49.—RELATIONS BETWEEN CREST STAGES ON THE MIAMI RIVER AT SIDNEY, PIQUA, AND TADMOR.

that the crest stage frequently occurs at Tadmor at the same time as at Sidney.

Forecasts of stages at Dayton are based on the estimated crests at the upper stations, proper allowance being made for lack of coordination of crests from the three streams. Wolf Creek is so steep, so short, and its drainage area so small, in comparison with the Stillwater, Mad, and Miami Rivers, that its flood runoff always passes Dayton several hours before the crests from the other three streams arrive. Only in very exceptional cases does any appreciable amount of flood runoff from the Wolf Creek valley reach Dayton at the time the Dayton crest is attained.

The maximum discharges from the Stillwater, Miami, and Mad Rivers do not reach Dayton in any definite order, although the crest discharge from the upper Miami practically always arrives later than that from one of the other two streams. The exact order of arrival varies with the rainfall intensity, location of most intense precipitation, and time of occurrence on the different areas. During the storm of July 7 to 8, 1915, in which practically all of the rain fell between the hours of 9 and 10 p.m. of the 7th, at all stations in the valley, the crest discharge from the Stillwater River reached Dayton about 24 hours after the rain had ceased, that from the Mad River arrived in about 16 hours, and that from the upper Miami, in about 29 hours. During the storm of May 6 to 7, 1916, in which practically all of the precipitation occurred in the night of the 6th and 7th, the crest discharge from the Stillwater River arrived at Dayton about 23 hours after the rain ceased, that from the Mad River arrived in about 25 hours, and that from the Miami, in about 29 hours. The difference in the time of arrival at Dayton of the crest discharge from Mad River during these two floods is found in the location of the most intense precipitation. During the May storm the heaviest rainfall in the Mad River Valley occurred near Urbana, about 40 miles by river from Dayton, while during the July storm it fell near Springfield, only about 25 miles from Dayton.

Having estimated the maximum stage to be reached at Dayton, forecasts for Miamisburg and Franklin may be made by the aid of the crest relation diagrams shown in figure 50. Similar methods may be used for Middletown and Hamilton whenever the rainfall distribution is such that the crest stages at these places are caused by the flood runoff from the drainage areas

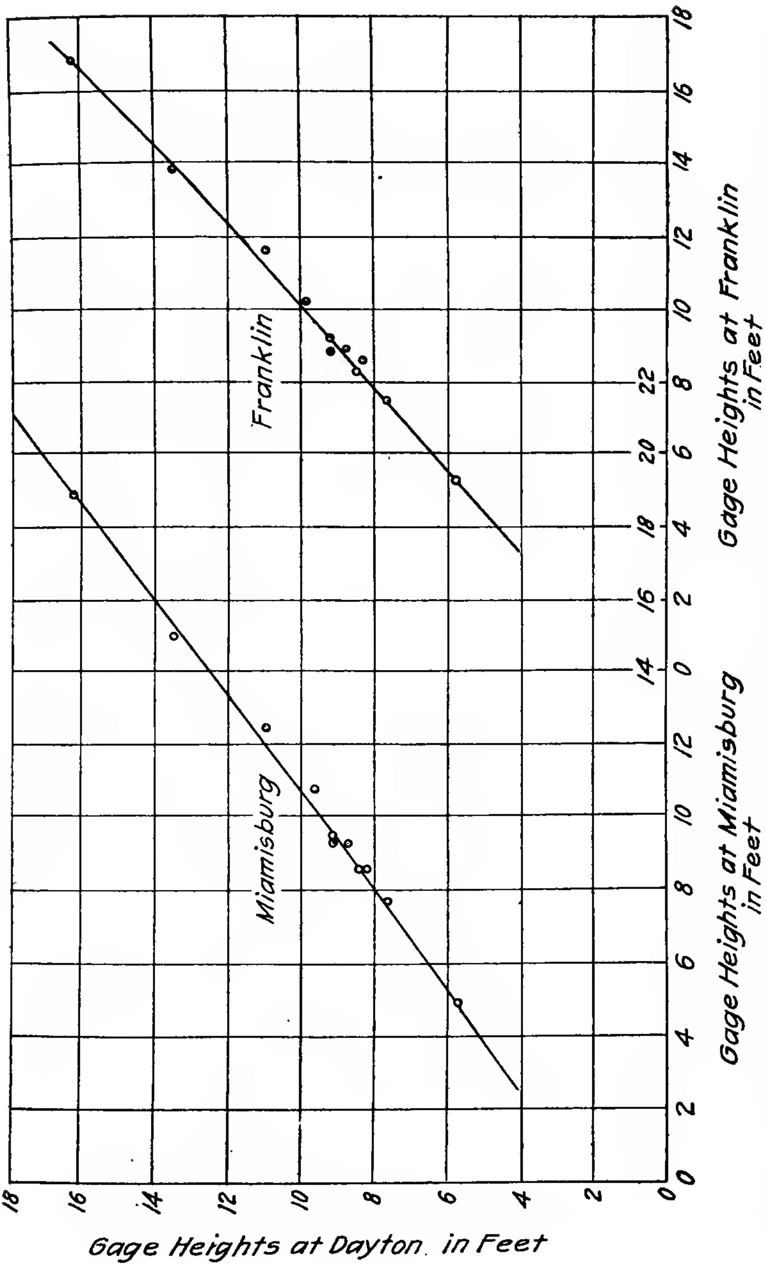

FIG. 50.—RELATIONS BETWEEN CREST STAGES ON THE MIAMI RIVER AT DAYTON, MIAMISBURG, AND FRANKLIN.

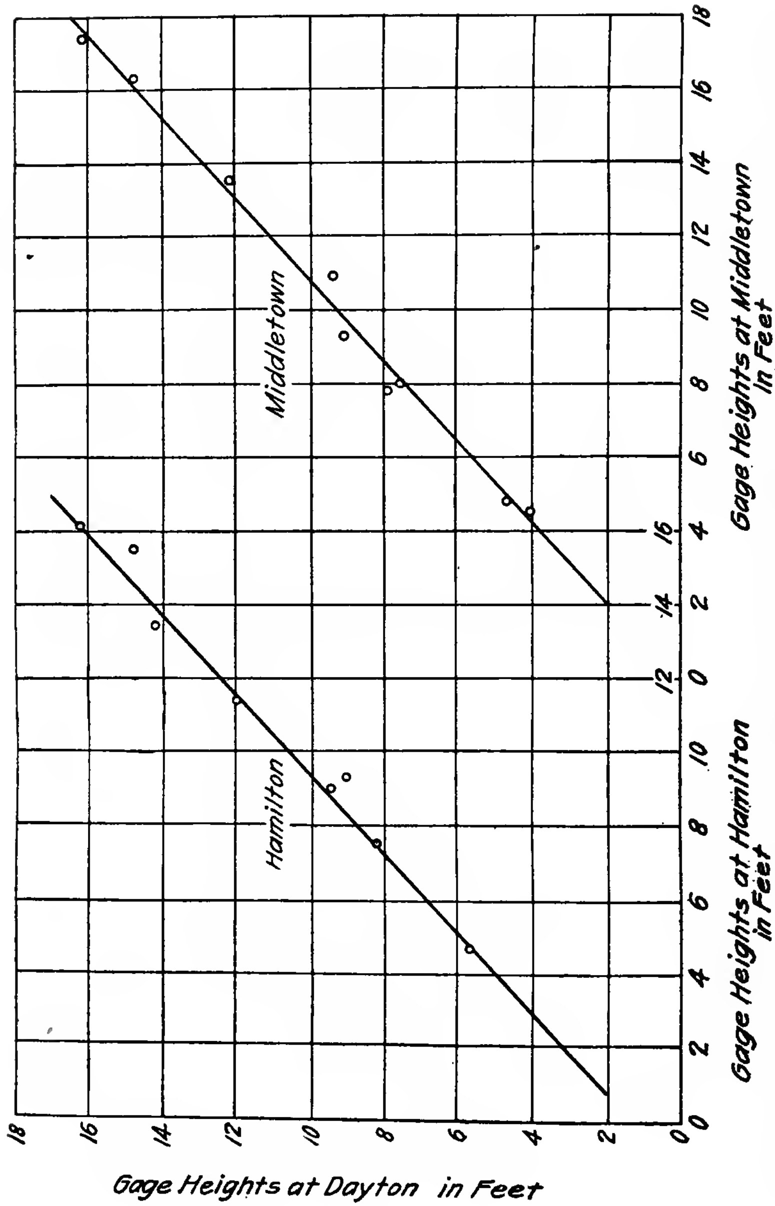

FIG. 51.—RELATIONS BETWEEN CREST STAGES ON THE MIAMI RIVER AT DAYTON, MIDDLETOWN, AND HAMILTON.

above Dayton. Diagrams for use in such instances are shown in figure 51. It frequently happens, however, that the crest stages at points below the mouth of Twin Creek are caused by the flood runoff from areas below Dayton rather than from those above. Of course, this happens more frequently as the distances below Dayton increase. During the storm of July, 1915, the crest at Hamilton was caused primarily by the flood runoff from the Seven Mile and Four Mile Creek valleys. In this instance the Hamilton crest occurred about 10 hours before the maximum stage was reached at Dayton.

The forecasting methods can probably be made plainer by describing a typical case. The flood of January 5, 1917, will be taken for this purpose. On the morning of January 5 the reports showed that the rainfall had averaged about 1.7 inches over the drainage area of the Stillwater River above West Milton, about 1.6 inches over the drainage area of the Miami River above Piqua, and about 1.4 inches over the drainage area of the Mad River above Springfield. For the Stillwater Valley it was estimated that 0.7 of an inch would be required to fill the soil and surface storage; and that the remaining inch, which would run off, would reach West Milton at a maximum rate of about a half an inch in 24 hours, or 7800 second feet. The rating table for the channel at West Milton showed that this would correspond to a stage of 8.0 feet. From the available records of previous floods it was estimated that this stage would be reached at about 3 p.m. By similar methods, making proper allowances for differences in topographical and geological conditions, it was estimated that a maximum rate of runoff of about 10,400 second feet, corresponding to a stage of about 7.0, would occur at Piqua at about 3 p.m.; and that a maximum rate of runoff of about 4,600 second feet, corresponding to a stage of about 7.5, would occur at Springfield at about 2 p.m.

From the known distances of these stations above Dayton and from the known slopes and velocities of the streams it was next estimated that the crest from the Stillwater River would reach Dayton first, that the crest from the Mad River would arrive next, and that the crest from the Miami River would arrive last. Since the quantity of water flowing in the Miami River was about a third greater than that in the Stillwater River and more than twice as great as that in the Mad River it was estimated that the maximum stage at Dayton would be reached when the crest flow from the Miami arrived, and that this would occur

at about 5 a.m. on the following morning. As the rainfall had been comparatively general over the entire valley it was estimated that the runoff from the drainage area below West Milton, Piqua, and Springfield would be more than sufficient to fill the storage space in the channels below the stages corresponding to the expected discharges. However, since the Stillwater and Mad Rivers would both be falling when the crest from the Miami arrived, it was estimated that the maximum discharge at Dayton would be about 21,000 second feet, or slightly less than the combined maximum discharges at West Milton, Piqua, and Springfield. This quantity corresponded to a stage of 8.9 feet and therefore a stage of 9.0 feet was predicted.

From crest relations during previous floods, it was then estimated that a stage of 10.0 feet would be reached at Miamisburg at 6 a.m., January 6; and that a stage of 9.0 feet would be reached at Franklin at 7 a.m. of the same day.

Forecasts were not being made for the dams at that time as construction work had not been started. At Hamilton the crest was caused by Seven Mile and Four Mile Creeks and was nearly reached at the time the forecasts were being made.

The following table compares the forecasted and actual conditions and also shows the time interval in hours between the time the forecasts were made and the time the crests were reached.

Table 41.—Forecasted and Actual Conditions During the Flood of January 5, 1917

Station	Forecast at 10 a. m. January 5			Actual			Advance Warning in Hours
	Stage	Time	Date	Stage	Time	Date	
West Milton	8.0	3 p.m.	Jan. 5	6.5	5 p.m.	Jan. 5	7
Piqua	7.0	3 p.m.	Jan. 5	5.9	5 p.m.	Jan. 5	7
Springfield	7.5	2 p.m.	Jan. 5	7.3	1 p.m.	Jan. 5	3
Dayton	9.0	5 a.m.	Jan. 6	9.1	1 a.m.	Jan. 6	15
Miamisburg	10.0	6 a.m.	Jan. 6	9.5	7 a.m.	Jan. 6	21
Franklin	9.0	7 a.m.	Jan. 6	9.2	9 a.m.	Jan. 6	23

The above described example is probably typical of the forecasting work in this valley. The predictions are not always so accurate for Dayton and Franklin; neither are they always so inaccurate for West Milton and Piqua. As a general rule, however, the forecasts for the locations on the Miami below the Stillwater and Mad Rivers are more certain than those for the upper stations.

APPENDIX

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The following bibliography contains references to the more valuable articles consulted in the preparation of this report. The literature on rainfall, runoff, evaporation, and related subjects is so voluminous that only the more important can be noted. As a rule references to articles dealing solely with rainfall, or stream flow, or the methods of measurement of either, have not been included. Some of the publications referred to have already been cited in the text.

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